CHAPTER 5

EXTERNAL COMPONENTS

5.1 Introduction

External components of an air cleaning system include fans, ductwork, dampers, louvers, stacks, instruments, and other miscellaneous accessories that are associated with the movement, control, conveying, and monitoring of the air or gas flow.

This chapter contains information on the design, fabrication, materials, and codes and standards requirements/considerations for air cleaning system external components for nuclear facilities. Additional information can be found in Chapters 2 and 4, as well as ASME Code AG-1.[1] Use of AG-1 requirements is mandatory for Safety Class and Safety Significant Systems and can be used as guidance for lower systems.

5.2 Ductwork

This section will address the functional design, mechanical design, materials, coatings, supports, acoustic considerations, leakage, vibration considerations, and applicable codes and standards for ductwork for nuclear facilities.

5.2.1 Functional Design

The sizing and layout of ductwork to provide desired air distribution, ventilation rates, transport velocities, and other functional requirements of the ventilation system are covered by the American Society of Heating Refrigeration and Air Conditioning Engineers (ASHRAE) handbook,[2, 3] the American Conference of Governmental Industrial Hygienists (ACGIH) *Industrial Ventilation*,[4] and American National Standards Institute (ANSI) Z9.2.[5] The purpose of this section is to review the physical aspects of the duct system in relation to nuclear air cleaning and treatment. The least expensive first-cost duct layout may not be the most economical when the total annual cost of operating the system is considered. Short-radius elbows and other shortcuts in ductwork may seriously increase system resistance, which could require, for example, the use of a larger fan and/or fan motor with resulting higher operating costs, or conversely, they could make it impossible for the system, as installed, to operate at the desired level of performance. The physical layout of ductwork in a building is often compromised to conform to the confines of a building structure or design. This may be unavoidable when installing new ducts in an existing building. In new construction, consideration should be given to providing adequate space and optimizing the duct layout configuration in the earliest phases of building layout, i.e., long before the building design has been finalized. Adequate access (as described in Chapter 4) to filter housings, fans, dampers, and other components is vital to maintainability and testability. Allowance of adequate space for well-designed elbows, transitions, and fan inlets and outlets is vital to proper operation.

5.2.2 Mechanical Design

Duct cost is influenced by the size and quantities of ductwork, construction materials, coatings used for protection against corrosion, construction methods (seams, joints, etc.), air-tightness requirements, erection sequence (including consideration of space limitations, post-erection cleaning requirements, etc.), and the number and type of field connections and supports (hangers, anchors, etc.) required. Consideration should be given to future modification, dismantling, and disposal of contaminated ductwork, particularly in the design of systems for U.S. Department of Energy (DOE) facilities, nuclear power plants, laboratories, experimental facilities, and other operations where change-out of the ductwork or removal for maintenance can be expected. Provision for adding on or changing ductwork is a consideration that is often overlooked in initial design.

Where space permits, a round duct is generally preferred to a rectangular duct because it is stronger (particularly under negative or collapsing pressure); is more economical for the high-pressure construction often required for nuclear applications; provides more uniform airflow; and is easier to join and seal than a rectangular duct. The principal disadvantages of round duct are that it makes less efficient use of building space and it is sometimes difficult to make satisfactory branch connections. Any duct system that carries radioactive material, or that could carry radioactive material, should be considered as a safety-related system. Specific requirements for the performance, design, structural load combinations, construction, inspection, and shop and field fabrication acceptance testing for ductwork, ductwork accessories, and ductwork supports can be found in American Association of Mechanical Engineers (ASME) AG-1, Sections SA and TA.[1]

The level of radioactivity will largely determine the quality of duct construction required. Although it is sometimes assumed that all leakage in negative pressure ductwork will be in-leakage, this is not necessarily true. In the event of fire or explosion in a contained space (room, enclosure, hot cell, glovebox, or confinement structure) served by the system, ductwork can become positively pressured, resulting in out-leakage. Out-leakage can also be caused by a rapidly closing damper or by dynamic effects (in a poorly laid-out system) under normal operating conditions. Under system shutdown conditions or during maintenance, the possibility of out-leakage from normally negative-pressure ductwork also exists. The engineer must consider these possibilities in the design and specification of permissible leak rates for negative-pressure portions of systems. Ducts should be sized for the transport velocities needed to convey all particulate contaminants without settling. Recommended transport velocities are given in Section 5 of *Industrial Ventilation.*[4] Ducts for most nuclear exhaust and post-accident air cleanup systems should be sized for a minimum duct velocity of 2,500 feet per minute (fpm).

ASME AG-1, Section SA,[1] contains recommendations for ductwork construction standards. This paragraph recommends the Sheet Metal and Air Conditioning Contractors' National Association (SMACNA)[6] ductwork construction standards. Note that these standards do not incorporate structural design requirements. These standards must be evaluated for structural capability and adjusted as necessary to meet the requirements of ASME AG-1,[1] and any other facility-specific requirements.

Tables 5.1 through 5.4 list a suggested methodology for sheet-metal gauges and reinforcements for negative pressure ducts operating at pressures below 2 in.wg negative. Suggested gauges and reinforcements for positive-pressure ducts are given in SMACNA standards.[7]

Table 5.1 – Recommended Sheet-Metal Thicknesses for Round Duct Under Negative Pressure

Negative Pressure in Duct	***Reinforcement Spacing***	***Sheet-Metal Thickness (U.S. gauge No.)[a] for Duct Diameter of***								
		4 in.	***8 in.***	***12 in.***	***16 in.***	***20 in.***	***24 in.***	***36 in.***	***48 in.***	***60 in.***
4 in.wg	∞[b]	24	24	20	18	16	14	10	8	4
	96	24	24	24	22	20	18	16	14	14
	48	24	24	24	24	24	22	20	18	16
	24	24	24	24	24	24	24	22	20	18
8 in.wg	∞	24	22	18	16	14	12	8	4	
	96	24	22	22	18	18	18	14	12	12
	48	24	24	24	22	20	20	16	14	14
	24	24	24	24	24	22	22	18	16	16

Negative Pressure in Duct	**Reinforcement Spacing**	***Sheet-Metal Thickness (U.S. gauge No.)*** [a] ***for Duct Diameter of***								
		4 in.	**8 in.**	**12 in.**	**16 in.**	**20 in.**	**24 in.**	**36 in.**	**48 in.**	**60 in.**
12 in.wg	∞	25	20	16	14	12	12	6	2	
	96	24	22	18	18	16	16	12	11	11
	48	24	22	22	20	18	18	14	14	12
	24	24	24	24	22	22	22	16	16	16
20 in.wg	∞	24	18	14	12	11	8	4		
	96	24	20	16	16	14	14	11	11	8
	48	24	22	20	18	16	16	14	12	11
	24	24	24	22	20	18	18	16	14	12
	12								20	16
1 psi	∞	20	14	12	10	8	6			
	96	24	18	16	14	12	12	10	8	6
	48	24	20	18	18	16	16	12	11	11
	24	24	24	22	20	18	18	14	12	12
	12								16	14
2 psi	∞	18	12	11	8	4	2			
	96	22	16	14	12	12	11	6	6	4
	48	24	18	16	14	14	12	10	8	6
	24	24	20	18	18	16	16	11	11	11
	12							14	12	12

Note: Factor of safety = 3 over code based on ultimate strength for ducts with diameters up to 24 inches and 5 over code for ducts with diameters over 24 inches based on paragraph UG-28 in Section VII of the ASME *Boiler and Pressure Vessel Code.*[8]

[a] Minimum sheet-metal thickness for shop-weld duct is No. 18 U.S. gauge. Minimum sheet-metal thickness for field-welded duct is No. 16 U.S. gauge.

[b] Where ∞ is shown, no reinforcement is required.

Table 5.2 – Recommended ASTM 36 Angles Reinforcement for Round Duct Under Negative Pressure

Negative Pressure in Duct	***Angle Size*** [a] ***for Duct Diameter of***								
	4 in.	**8 in.**	**12 in.**	**16 in.**	**20 in.**	**24 in.**	**36 in.**	**48 in.**	**60 in.**
4 in.wg	A	A	A	B	B	B	B	C	C
8 in.wg	A	A	A	B	B	B	B	C	C
12 in.wg	A	A	A	B	B	B	B	C	C
20 in.wg	A	A	A	B	B	B	B	C	C
1 psi	A	A	A	B	B	C	C	C	C
2 psi	A	A	A	B	B	C	C	D	D
4 psi	A	A	A	B	B	C	C	D	D

[a] Symbol for angle size (inches): A = 1 x 3/16; B = 1 1/2 x 1 1/2 x 1/4; C = 2 x 2 x 1/4; D = 2 1/2 x 2 1/2 x 1/4.

Source: Based on R. J. Roark, *Formulas for Stress and Strain*, 7th Edition, McGraw-Hill, 1989, Formula 12, Table XV. [9]

Table 5.3 – Recommended Sheet-Metal Thicknesses for Rectangular Welded Duct Under Negative Pressure

Negative Pressure in Duct (in.wg)	**Reinforced Spacing (in.)**	**Sheet-Metal Thickness [a] (U.S. gauge No.) [b] for Longest Side of Length**				
		12 in.	**14 in.**	**36 in.**	**48 in.**	**60 in.**
4	48	18	18	16	14	
4	24	18	18	18	16	16
4	12	18	18	18	18	16
8	48	18	14	12	12	
8	24	18	16	16	14	14
8	12	18	18	18	18	18
12	48	18	12	8	11	
12	24	18	16	12	12	12
12	12	18	18	18	18	18
20	48	14	11	6	6	
20	24	14	14	11	11	11
20	12	18	14	14	14	14
1 psi	48	12	10			
	24	16	12	11	10	
	12	18	14	12	11	
2 psi	48	12	10			
	24	14	11	10	8	
	12	16	12	11	10	

[a] For maximum deflection of 1/16 inch per foot in the long dimension.

[b] Minimum sheet-metal thickness for filed-welded duct is No. 16 U.S. gauge.

Source: Based on R. J. Roark, Flat plate formula for edges held but not fixed, *Formulas for Stress and Strain*, 7th Edition, McGraw-Hill, 1989, p. 246.[9]

Table 5.4 – Recommended ASTM A 36 Angle Reinforcement for Rectangular Ducts Under Negative Pressure

Negative Pressure in Duct (in.wg)	**Angle Size [a] of Ducts with a Maximum Panel Size of**											
	12 in. by				**24 in. by**				**48 in. by**			
	12 in.	**24 in.**	**36 in.**	**48 in.**	**60 in.**	**24 in.**	**36 in.**	**48 in.**	**60 in.**	**36 in.**	**48 in.**	**60 in.**
4	E	E	E	F	F	E	G	G	G	H	H	H
8	E	E	E	F	F	E	G	G	G	H	H	H
12	E	E	E	F	F	E	G	G	G	H	H	H
20	E	F	H	H		G	H	J				
1 psi	F	G	H	J		H	J	K				
2 psi	G	H	J	L		J	K	L				

Note: Based on uniformly loaded beam with 50 percent simple support, 50 percent fixed ends, and deflection of 1/8 inch per foot.

[a] Symbol for angle size (inches): E = 1 x 1 x 1 3/16; F = 1 1/4 x 1 1/4 x 3/16; G = 1 1/2 x 1 1/2 x 3/16; H = 2 x 2 x 3/16; J = 2 1/2 x 2 1/2 x 1/4; K = 3 x 2 1/2 x 1/4; L = 4 x 3 x 3/8.

Table 5.5 – Guide for Selecting Recommended Duct Construction Levels for Various Applications in Nuclear Facilities [a]

Contamination Level and/or Function [b]	Operating Mode [c]	System Type, Duct Location Outside Contained Space, All Systems, Duct Located in–			Zone I	HVAC, [d] Supply, [e] Recirculating Portion within Contained Space
		Zone IV	Zone III	Zone II		
None, supply, HVAC	A	1	1	2	2	2
	B	1	1	1	1	1
Low (class 4)	A	3	2	2	2	2
	B	1	1	2	2	1
Moderate (class 3)	A	4	3	2	2	2
	B	4	2	2	2	1
High (class 2)	A	4	4	4	4	2
	B	4	4	4	4	2
Very high (class 1)	A	4	4	4	4	2
	B	4	4	4	4	2
Process off-gas	A	5	5	5	4	2
	B	5	5	4	4	2
Controlled atmosphere [f]	A	5	5	5	5	5
	B	5	5	5	5	5

[a] Duct construction level: 1, SMACNA low velocity; 2, SMACNA, high velocity; 3, SMACNA high velocity; 4, welded; 5, pipe or welded duct, zero leak.

[b] Contamination levels from Tables 2.3 for classes 2, 3, and 4.

[c] Operating mode: (A) system to operate following upset or accident; (B) system shutdown in event of upset or accident.

[d] HVAC, building enclosure zones from Section 2.2.9.

[e] Contained space: The building area or enclosure served by the system.

[f] Inert gas, desiccated air, or other controlled medium.

Table 5.6 – Recommended Maximum Permissible Duct Leak Rates [a] at 2 in.wg Negative (by methods of ASME N510)[10]

Duct Class	Maximum Permissible Leak Rate
Level 1	5 percent of system airflow per minute
Level 2	1 percent of system airflow per minute
Level 3	0.2 percent of volume per minute [b]
Level 4	0.1 percent of volume per minute [b]
Level 5	Zero detectable leak at any test pressure up to 20 in.wg
Recirculating	Leak test not required if totally within contained space served by air cleaning system

[a] Maximum permissible leak rate at pressure greater than 2 in.wg is found from the equation.

$$L_p \times L_2 \sqrt{P'/2}$$

where

L_p = permissible leak at higher pressure,
L_2 = permissible leak at 2 in.wg from table,
P' = higher pressure.

[b] Based on volume of portion of system under test.

For ducts that are fabricated by welding, a minimum of No. 16 U.S. gauge sheet metal is recommended because of the difficulty of making reliable welds in thinner material. Section 5.10 of the ANSI N509 recognizes several levels or grades of duct construction but does not define them (in terms of specific requirements) or distinguish clearly between them. Because a nuclear facility may contain spaces of widely differing potential hazard levels (see confinement zoning discussion, Section 2.2.9), the type of duct construction required may vary from one part of the plant to another. The following questions, as a minimum, must be answered to establish the type of duct construction needed for a particular application.

- Is the system nuclear-safety-related?
- If the system is nuclear-safety-related, is the level of radiation that exists in the duct, or the level that could exist in the duct in the event of a system upset, low, intermediate, or high?
- Must the air cleaning system remain operable in the event of a system upset (power outage, accident, malfunction) or can it be shut down?
- Where will the ductwork be located in relation to: (1) the contained space served by the system, and (2) the occupied spaces of the building? [Building spaces that are not normally occupied, but are occasionally entered for repair or service of equipment, are considered "occupied."]
- Is the system once-through or recirculating?
- Is it a safety-related feature system that is intended to mitigate the consequences of an accident?
- What are the environmental considerations (e.g., pressure, temperature, corrosion, etc.)?

Depending on the answers to these questions, the duct should be constructed to conform to one of the several grades outlined in **Table 5.5** and the leaktightness recommendations of ASME AG-1, Section SA.[1] Recommended construction requirements are categorized as described below.

Level 1. In accordance with SMACNA's "HVAC – Systems-Duct Design," (with the exceptions that button-punch and snap-lock seam and joint construction are not permitted), these constructions are considered unsuitable even for low-pressure construction.[7] Companion-angle or bolted (or screwed) standing-seam transverse joints are recommended. Standing edges of seams or joints and reinforcement should be on the outside of the duct (**Figure 5.1**).[7] [Note: Use of Level 1 ductwork is limited to systems serving administrative areas and other non-safety-related applications in which maximum static pressure does not exceed 2 in.wg.] See Figure 5.1.

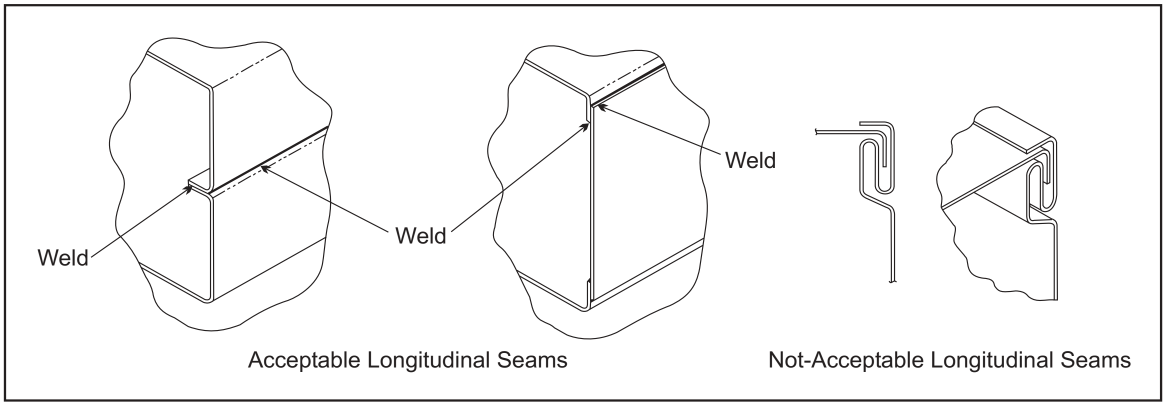


Figure 5.1 – Leakage Class 1 Duct Seams

Level 2. In accordance with SMACNA's "HVAC Systems-Duct Design,"[7] the use of Level 2 ductwork is limited to systems serving administrative areas, as well as Secondary and Tertiary Confinement Zones in which the radiotoxicity of materials that are handled or could be released to the ductwork does not exceed hazard class 2 (see Tables 2.3 through 2.5), and in which negative pressure does not exceed 10 in.wg. The following exceptions apply: (1) button-punch and snap-lock construction are not permitted; (2) only bolted flanged joints, companion-angle flanged joints, welded-flanged joints, or welded joints are permitted for transverse connections; (3) tie rods and cross-braking are not permitted on negative-pressure ducts; (4) standing edges and reinforcement of seams and joints should be on the outside of ducts only; (5) sheet-metal thickness and reinforcement of negative-pressure ducts should be in accordance with ASME AG-1, Section SA-4000,[1] and (6) radiation-resistant sealants (e.g., silicone room-temperature vulcanizing) are used as required in the makeup of nonwelded seams and in penetrations of safety-related ductwork.

Level 3. This is the same as Level 2, with the exception that: (1) transverse joints must have a full-flanged face width and use 1/4-in.-thick gaskets made of American Society of Testing and Materials (ASTM) D1056[11] grade 2C2 or 2C3 cellular neoprene; grade 2C3 or 2C4, 30 to 40 durometer, Shore-A, solid neoprene; or an equivalent silicone elastomer with interlocking notched corners; and (2) nonwelded longitudinal seams, transverse joints, or the entire exterior may have hard-cast treatment (polyvinyl acetate and gypsum tape system) or comparable fire-resistant, corrosion-resistant, radiation-resistant, nonpeeling, leaktight treatment.

Level 4. This level requires all-welded construction with sufficient mechanical transverse joints to facilitate coating (painting), erection, and future modification and/or dismantling. Mechanical transverse joints must conform to **Figure 5.2**. For sheet-metal thickness and reinforcement, see ASME AG-1, Section SA.[1] Specific guidance is provided in nonmandatory Appendix SA-C, Section C-1300.[1]

Level 5. Level 5 ductwork meets requirements for leaktightness as determined in ASME AG-1, Section SA, Nonmandatory Appendix SA-B[1] or the requirements of the *American National Standard for Pressure Piping*, ASME B31.1,[6] or the ASME *Boiler and Pressure Vessel Code.* [8]

See **Figures 5.2** through **5.4** for examples of seams, joints, gaskets, and sealing of companion angle joint corners.

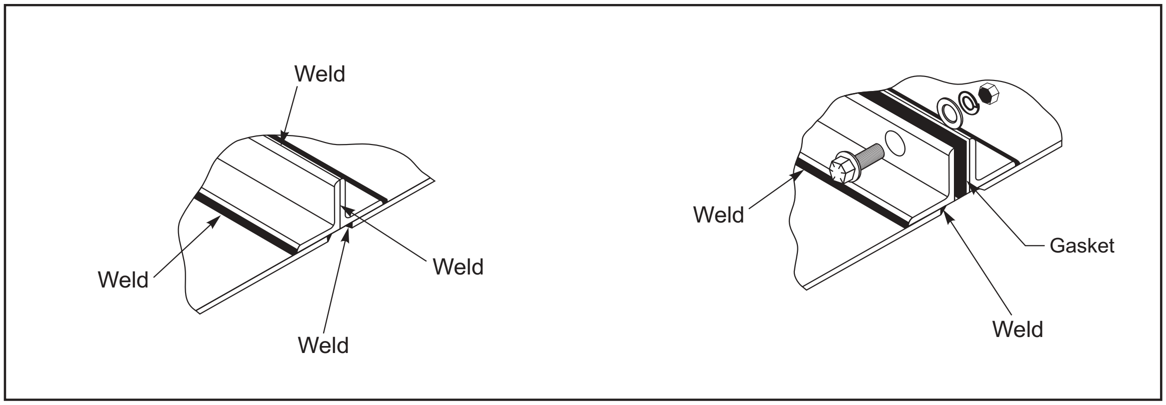


Figure 5.2 – Acceptable Transverse Joints

5.2.3 Engineering Analysis

When sheet-metal thickness and reinforcements are established from engineering analysis rather than from Tables 5.1 to 5.7, a design pressure of at least 1.25 times the normal operating pressure is necessary for level 1, 2, and 3 construction. A design pressure of 1.5 times the maximum negative pressure that can exist in the particular run of duct, under the most adverse conditions to which it can be subjected under any conceivable

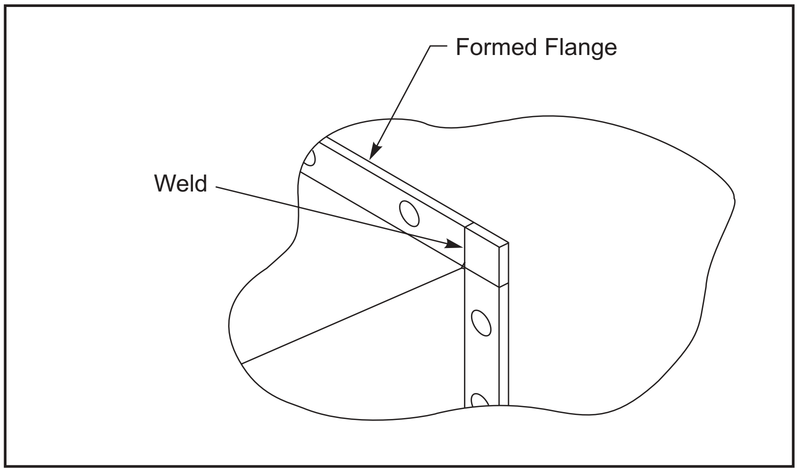


Figure 5.3 – Acceptable Formed Flange

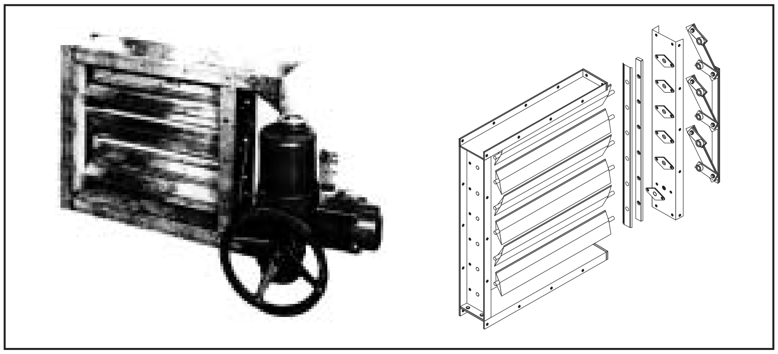


Figure 5.4 – Control Dampers

conditions, including the Design Basis Accident (DBA) and safe shutdown earthquake, is recommended. The maximum negative pressure is generally the fan shutoff pressure. In the engineering analysis, the following loadings should be considered as applicable to the particular system under consideration:

1. Differential pressure across the duct wall, as affected by maximum internal and external pressures that could prevail during testing and under normal and abnormal operating conditions, and any increase or decrease in the pressure due to inadvertent closure of a damper or plugging of an internal component. For ductwork located within the containment vessel of a reactor, the external pressure under DBA conditions, due to the lag of pressure rise within the ductwork during the pressure transient in the containment vessel, must also be considered (such overpressures may be alleviated through the use of pressure-relief dampers that discharge to the containment space).
2. Effects of natural phenomena, including tornado and earthquake, for safety class-ductwork.
3. Thermal expansion.
4. Weight of the ductwork, including all attachments.
5. Weight of personnel walking on large ductwork only. Where this situation is likely to occur, duct sections with exposed top surfaces should be capable of supporting a 250-pound weight concentrated midway between the hangers or reinforcement, without permanent deformation. The out-of-roundness produced by such loading could lead to a sudden collapse of round duct when operating under negative pressure.

A maximum allowable stress of 0.7 times the elastic limit is recommended for the design of ductwork maximum deflections under normal operating conditions and should be:

Rectangular duct: 0.125 inch per foot of maximum unsupported panel span in the direction of airflow, but not greater than 0.75 inches. Defection of reinforcement -0.125 inch per foot of span, but not more than 0.75 inches across total span.

Round duct: 0.025 inch per foot of diameter, but not more than 0.5 inch at any point.

5.2.3 Engineered Ductwork

When sheet metal or piping thicknesses and reinforcement are established from analysis other than as required by ASME AG-1,[1] SMACNA standards,[7] or other referenced documents, the design should be in accordance with the criterion found in ASME AG-1, Sections AA and SA.[1] In the engineering analysis, the following are examples of loads that should be considered potentially applicable to the system under consideration:

- **Additional Dynamic Loads.** These loads result from system excitation caused by structural motion such as relief valve actuation and hydrodynamic loads due to design basis accidents (DBAs).

- **Constraint of Free End Displacement Loads.** These loads are caused by the constraint of free-end displacement and are caused by thermal or other displacements.

- **Dead Weight.** These loads are the weight of equipment and ductwork, including supports, stiffeners, insulation, internally mounted components, externally mounted components and accessories, and any contained fluids.

- **Design Pressure Differential.** These loads are dynamic pressures caused by the DBAs, and intermediate or small break accidents.

- **Design Wind.** These loads are produced by design hurricanes, tornadoes, or other abnormal, infrequently occurring meteorological conditions.

- **External Loads.** These are applied loads caused by piping, accessories, or other equipment.

- **Fluid Momentum Loads.** These are loads other than those previously listed, such as the momentum and pressure loads caused by fluid flow.

    - **Live Load (L).** Such loads occur during construction and maintenance and other loads due to snow, ponded water, and ice.

    - **Normal Loads (N).** These loads include normal operating pressure differential, system operating pressure transients, dead weight, external loads, and inertia loads.

    - **Normal Operating Pressure Differential (NOPD).** This is the maximum positive or negative pressure differential that may occur during normal system operation, including startup and testing. These include the pressures resulting from normal airflow and damper or valve closure.

    - **Seismic Load.** These loads result from the operating basis earthquake (OBE) or the safe shutdown earthquake (SSE). These seismic forces are applied in the direction that produces the worst-case stresses and deflections.

    - **System Operating Pressure Transient.** These overpressure transient loads are caused by events such as rapid damper or valve closure, rapid plenum or housing door closure, or other loads of this type that result in a short duration pressure differential (spike).

Additional information concerning the structural design and supports for ductwork and supports can be found in ASME AG-1, Section AA.[1]

5.2.4 Applicable Codes, Standards, and References

There are many codes, standards, and other references that are applicable to ductwork design. A complete, detailed listing is available in ASME AG-1, Sections AA and SA.[1]

5.2.5 Materials of Construction

Ductwork may be constructed from painted or coated carbon steel, galvanized steel, aluminum, stainless steel, or any combination of these materials as required to resist corrosion in the service environment. Glass-fiber-reinforced plastic (GFRP) and epoxy ducts have been used in corrosive environments where fire and safety requirements permit, and may be less expensive than stainless steel, lined carbon steel, or epoxy- or vinyl-coated carbon steel. Although the GFRP duct has been approved by the National Fire Protection Association and Underwriters Laboratories (UL) for commercial and industrial use, even high-temperature resins will soften under brief exposure to temperatures of 350 to 450 degrees Fahrenheit. Softening of the GFRP duct can lead to rapid collapse or distortion, followed by loss of air cleaning function. GFRP and other plastic ductwork should not be used for Level 3, 4, or 5 construction and should be used with caution for Levels 1 and 2.

5.2.6 Paints and Protective Coatings

Coating and paint requirements must be consistent with the corrosion that can be expected in the particular application and with the size of the duct. Corrosion- and radiation-resistant paints and coatings should, as a minimum, meet the requirements of ASME AG-1,[1] and ASTM D5144, *Standard Guide for Use of Protective Coating Standards in Nuclear Power Plants*.[12] Unless special spray heads are used, spray coating of the interior of ducts smaller than 12 inches in diameter is often unreliable because it is difficult to obtain satisfactory coating and to inspect for defects. The interior of a duct sized 8 inches and smaller cannot be satisfactorily brush-painted; therefore, dip coating is recommended. Ducts to be brush-painted should be no longer than 5 or 6 feet to ensure proper coverage. When special coatings such as high-build vinyls and epoxies are specified, the designer must keep in mind that difficulties in surface preparation, application, and inspection may increase the cost of coated carbon steel to the point that stainless or galvanized steel may be more economical. In addition, stainless or galvanized steel may provide better protection. Note that high-build coatings and paints can be damaged during handling and shipping (as well as during construction, maintenance, repair, and testing/surveillance). Corrosion can begin under such damaged areas without the user's knowledge. Painted and coated ductwork must be inspected carefully during the painting (coating) operation, as well as on receipt. Galvanized coatings and plates should also be carefully inspected, particularly on sheared edges and welds.

5.2.7 Supports

Nonsafety class ductwork can be hung, supported, and anchored in accordance with the recommendations of Chapter 5 of the SMACNA *HVAC—Duct Design*,[7] with the following exception: anchors and attachments which rely on an interference-fit between, or deformation of, the base material (concrete roof deck, beam, etc.) and the attachment device (as is the case for power-actuated drive bolts and studs and for concrete anchors) should not be used for safety-related ductwork. Support requirements for safety class ducts and other ductwork that must remain in place in the event of an earthquake or major accident must be established by modeling or engineering analysis. Such analysis must be based on the inputs (forces, accelerations) to the building element to which the duct is fastened or from which it is hung (i.e., floor, wall, roof deck, etc.) that will be produced by the DBA or SSE, or both. Non-Engineered Safeguard Feature (ESF) ductwork located above or adjacent to other safety class equipment of the facility, which could damage such equipment if it fell, is also subject to this restriction.

5.2.8 Thermal Insulation and Acoustic Considerations

Acoustic linings and silencers are not permitted in safety-related ducts or ducts which carry, or may carry, moisture. Acoustic treatment, if required, must be attached to the exterior of the duct.

Thermal insulation, acoustic linings, and duct silencers are not permitted in ducts that carry or may carry moisture, corrosive fumes, or radioactive air or gas. Thermal insulation and acoustic treatment, if required, must be attached to the exterior of the duct and secured in such a manner that it cannot fall off during applicable DBAs.

5.2.9 Ductwork Leakage

The leaktightness of ductwork is extremely important, particularly in systems that carry or could potentially carry radioactive material. Duct leakage wastes power and thermal energy (the energy required to heat, cool, or dehumidify air), causes noise, prevents correct airflow to outlets from inlets, makes system balancing and temperature and humidity control difficult, and produces dirt collections and radioactive contamination at leakage sites.

Even one percent is excessive for systems that carry or could potentially carry intermediate- to high-level radioactivity. Leak rates based on the percentage of airflow are meaningless and are subject to misinterpretation. Duct tightness is generally tested by sealing off sections of the system and individually testing them by either the direct-measurement or pressure decay method of ASME N510.[10] With such procedures, a leakage criterion based simply on percentage of airflow can produce anomalous results. By such a criterion, two duct systems build to the same construction standards and having the same volume and surface area but different airflow rates could have widely differing permissible leakages. Conversely, if the airflow rates are the same but the volumes differ, they could have widely differing permissible leakages. For this reason, a permissible leakage based on duct volume or a permissible leakage based on the surface area of the pressure boundary of the section under test is recommended. Table 5.6 gives permissible leak rates for the various levels of construction, including the values that have been recommended over the years for nuclear grade ductwork. The values for levels 3, 4, and 5 ductwork are more stringent than those recommended for ductwork in nuclear power plants by ASME N509.[13]

In tests conducted at a DOE facility, sections of level 2 ductwork tested alternately at 2.5 in.wg positive and 2.5 in.wg negative by the pressure-decay method showed no pressure loss in 15 minutes under positive pressure, but a loss of 2 in.wg in 15 minutes under negative pressure. This tendency for the same ductwork to leak substantially more under negative pressure than under positive pressure is confirmed by SMACNA.[7] It is recommended that leak tests be made under negative pressure if possible and at the normal discharge pressure or suction pressure of the fan insofar as is practicable. These leak rates are predicated on the potential for outleakage of contamination to occupied areas of the facility should be ductwork or filter housing become pressurized under system upset conditions. Leak testing should be performed in accordance with the methods provided in ASME N509[13] and N510,[10] with additional requirements for safety-related systems contained in ASME AG-1, Section SA-5300, and Section TA.[1]

Vibration and Flexible Connections

Vibration and pulsation can be produced in an air or gas cleaning installation by turbulence generated in poorly designed ducts, transitions, dampers, and fan inlets, and by improperly installed or balanced fans and motors. Apart from discomfort to personnel, excessive vibration or pulsation can result in eventual mechanical damage to system components when vibrational forces become high or when acceleration forces (e.g., from an earthquake or tornado) coincide with the resonant frequencies of those components. Weld cracks in ducts, fan housings, and component mounting frames may be produced by even low-level local vibration if sustained, and vibrations or pulsations that produce no apparent short-term effects may cause serious damage after long duration.

Vibration produces noise that can range from unpleasant to intolerable. An important factor in preventing excessive vibration and noise is planning at the stage of initial building layout and space allocation to ensure adequate space is provided for good aerodynamic design of ductwork and fan connections. Spatial conflicts with the process and with piping, electrical, and architectural requirements should also be resolved during early design so that the compromises that are so often made during construction, which often lead to poor duct layout and resulting noise and vibration, can be avoided. Ducts should be sized to avoid excessive velocities while maintaining the necessary transport velocities to prevent the settling out of particulate matter during operation.

Fan vibration can be minimized via vibration isolators and inertial mountings. It should be noted that use of these devices must be carefully coordinated with the structural designers because seismic design requirements sometimes prohibit their use. Some structural designers require hard-mounting of fans where continued operation during and after an earthquake must be considered.

To minimize transmission of vibration from fans, flexible connections between fans and ductwork are often employed and recommended. These must be designed to resist the high static pressures often incurred in HVAC systems, particularly in those parts of the system under negative pressure, e.g., near the inlet of large exhaust fans. In addition, consideration must be given to the leakage and potential failure that can occur with flexible connections. Commercial applications commonly use heavy-duty canvas. Canvas is not suitable for nuclear facility applications. Consideration should be given to using at least two layers of a leak-proof material (e.g., rubber or neoprene, sometimes reinforced with higher-strength materials such as fiberglass and Kevlar®).

Finally, the ductwork system must be balanced after installation, not only to ensure the desired airflows and resistances, but also to "tune out" any objectionable noise or vibration that may be inadvertently introduced during construction. DOE nuclear facilities should adopt and apply the concepts and practices of predictive maintenance. DOE Order 433.1[14] requires all DOE contractors to institute a predictive maintenance program.

5.3 Dampers and Louvers

5.3.1 Damper Descriptions

By definition, a damper is a device used to control pressure, flow, or flow direction in an air or gas system. See ASME N509[13] and AG-1, Section DA.[1] Different types of dampers can be used, depending on specific functional requirements. **Table 5.7** lists the types of dampers and their functions, and **Table 5.8** lists the damper configurations. **Figures 5.5, 5.6, and 5.7** are examples of industrial-quality dampers. Selection of the proper damper type and blade configuration is important to achieve the required damper performance. The type and configuration of damper can significantly impact pressure drop, leakage rates, and controllability.

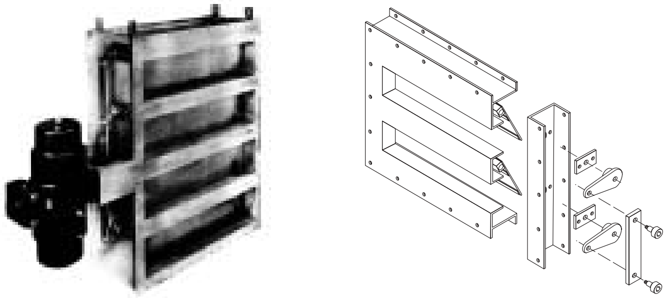
Table 5.7 – Classification of Dampers by Function

Designation	**Function**
Flow control damper	A damper that can be continuously modulated to vary or maintain a given level of airflow in the system in response to a feedback signal from the system, or from a signal fed to the damper operator via a manually actuated control or switch.
Pressure control damper	A damper that can be continuously modulated to vary or maintain a given pressure or pressure differential in the air cleaning system or in a building space served by the system in response to a pressure signal.
Balancing damper	A damper set (usually manually) in a fixed position to establish a baseline flow or pressure relationship in the air cleaning system or in building spaces served by the system.
Shutoff damper	A damper that can be completely closed to stop airflow through some portion of the system, or opened partially or fully to permit airflow (the flow control damper may also serve this function).
Isolation damper	A high-integrity shutoff damper used to completely isolate a portion of a system from a contained space, or from the remainder of the system with a leaktight seal. In the case of confinement isolation, butterfly valves are used in lieu of dampers.
Back-draft or check damper	A damper that closes automatically or in response to a signal to prevent flow reversal.
Pressure-relief damper	A damper that is normally closed, but will open in response to overpressure in the system or in the contained space served by the system to prevent damage to the system.
Fire and smoke damper	A damper that interrupts airflow automatically in the event of fire or smoke so as to restrict the passage of flame or smoke through the air system, in order to maintain the integrity of the fire-rated partition or other fire-rated separation.
Tornado damper	A damper that controls airflow automatically to prevent the transmission of tornado pressure surges.

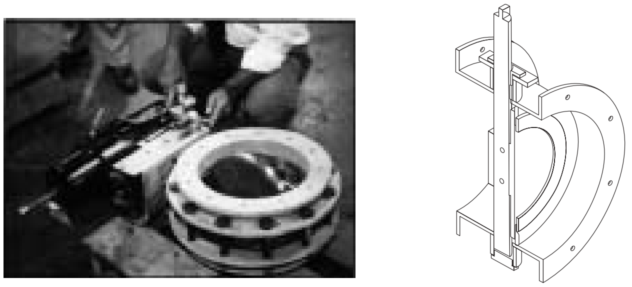
Table 5.8 – Classification of Dampers by Configuration

Designation	**Configuration**
Parallel blade damper	A multi-blade damper with blades that rotate in the same direction (AMCA 500).[a]
Opposed blade damper	A multi-blade damper having adjacent blades that rotate in opposite directions (AMCA 500).[a]
Butterfly damper	A heavily constructed damper, often a valve, that is used in piping or duct systems and is usually round in cross-section and designed for high-pressure service (25 psi minimum pressure rating), with one centrally pivoted blade that can be sealed.
Single-blade balanced damper	A damper, usually round in cross-section, with one centrally pivoted blade.
Single-blade unbalanced damper	An accurately fabricated, often counterbalanced damper, usually rectangular in cross-section, with one eccentrically pivoted or edge-pivoted blade.
Folding blade, wing blade, or check damper	A damper with two blades pivoted from opposite sides of a central post that open in the direction of airflow.
Poppet damper	A weight or spring-loaded poppet device that opens when the pressure differential across it exceeds a predetermined value.
Slide or gate damper	A damper similar to a gate valve, with a single blade that can be retracted into a housing at the side of the damper to partially or fully open the damper.

[a] AMCA 500-D-1998, *Laboratory Methods of Testing Dampers for Rating,* Air Moving and Conditioning Association, Arlington Heights, IL, 1998.[15] Also AMCA 500-L-1999, *Laboratory Methods of Testing Louvers for Rating,* Air Moving and Conditioning Association, Arlington Heights, IL.[15]



(a) Bubbletight Dampers (rectangular)



(b) Bubbletight Dampers (round)

Figure 5.5 – Bubbletight Dampers

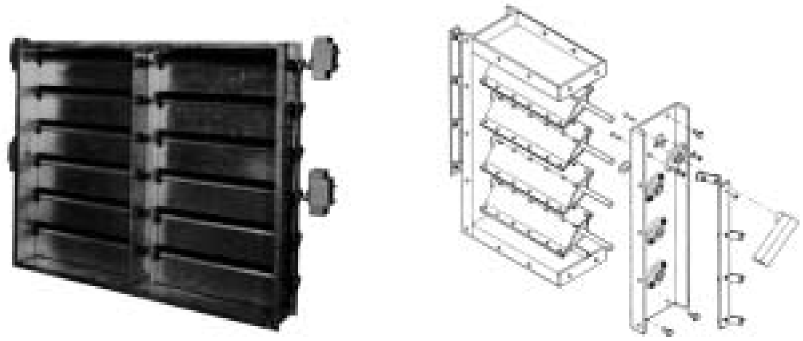


Figure 5.6 – Backdraft Dampers

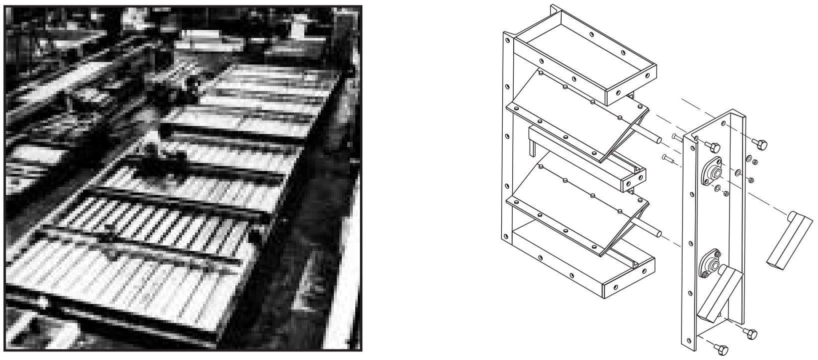


Figure 5.7 – Tornado Dampers

The following factors must be considered in the selection or design of dampers for nuclear applications:

- Damper function,
- Construction type,
- Dimensions and space limitations,
- Pressure drop for open position and across closed damper,
- Normal blade operating position,
- Method of mounting damper,
- Blade orientation relative to damper frame,
- Operator type and power source,
- Seismic requirements,
- Requirements for position indicator,
- Limit switches and other appurtenances,
- Damper configuration,
- Permissible leakage through closed damper,
- Space required for service,
- Airstream environmental parameters (temperature, pressure, relative humidity, etc.),
- Damper orientation in duct,
- Airflow direction and velocity,
- Failure of mode and blade position,
- Maximum closing and opening times, and
- Shaft sealing method.

5.3.2 Design and Fabrication

In conventional air conditioning and ventilating applications, damper procurement has been generally accomplished by specifying little more than the manufacturer's make and model number or “approved equal.” This is inadequate for nuclear and other potentially high-risk applications. Dampers for nuclear applications should be designed and constructed in accordance with ASME AG-1, Section DA.[1]

Clear, concise specifications must be established for mechanical strength, for leakage rate at maximum (i.e., DBA) operating conditions, and for performance under required operational and emergency conditions. The operability of linkages must be assured through specification of, and requirement for, cycling at minimum torque requirements under full load. Static testing of the closed damper should be required, where applicable, for those to be used in critical applications to verify strength and leaktightness. All features important to proper operation should be stipulated in detail, including construction materials, permissible lubricants, bearings, blade design and edgings (if permitted), indicating and locking quadrants, supports, operator type and capability, and the accessibility of operators, linkages, blades, and bearings for maintenance. A checklist of the minimum requirements that must be included in a damper design specification is given in ASME AG-1, Section DA.[1]

5.3.2.1 Structural Design

Previous editions of this handbook categorized dampers by construction type. Present construction criteria specified in Section DA of ASME AG-1[1] are categorized by performance requirements (seat or frame leakage, application, function, and loading combinations), as discussed in Section 5.3.3.

The structural design of dampers should be in accordance with Sections AA and DA of ASME AG-1[1] for the loading combinations and the service levels specified in the design specifications. The design should be verified by analysis, testing, or a combination of both for those dampers that must remain functional or retain their structural integrity during a design basis earthquake (DBE).

5.3.2.2 Design and Construction Considerations

A very important part of damper design is determination of damper torque and sizing and selection of damper actuator for the maximum torque. Actuator torque should be selected for a minimum of 1.5 times the damper maximum torque to provide margin and allow for degradation over the life of the damper. Actuators should be evaluated for damper blade movement in both directions, at the beginning of blade movement, and while stroking blades through the full cycle of movement.

The linkage mechanism must be designed to transmit actuator torque for the blades to achieve required leakage performance. Ganging of more than two damper sections for operation by one actuator is not recommended because of the potential problems in transmitting the torque equally to each section and blade. Experience has shown that ganging multiple damper sections has led to twisting of drive shafts and overtorquing of the blades closest to the actuator.

Conversely, ganging two or more actuators per damper can also cause operating problems if the actuators are not synchronized. Some blades may close tighter than others, since not all of the blades are linked together. Damper actuators should be factory-mounted whenever possible. Wherever actuators must be installed in the field or removed for maintenance, manufacturer's installation instructions should identify the necessary amount of retorquing required to achieve design leakage. The actuator shaft, coupling, and blade shaft should be “match-marked” for easy installation.

Seals are another important component of damper design. Dampers designed for low leakage rely heavily on blade and jamb seals to limit leakage. Seals typically are either metal (e.g., stainless steel) or elastomer. Design of seals should consider the required life of the damper assembly to minimize maintenance. For this reason, stainless steel seals are recommended for low leakage dampers in contaminated airstreams whenever possible (see Section DA of ASME AG-1).[1] To control frame leakage, either stuffing boxes or frame cover plates are required.

5.3.2.3 Damper Operators

Damper operators can be one of three types: pneumatic, electric, or electrohydraulic, as described below.

Pneumatic. These damper operators are used whenever controls rely primarily on compressed air (pneumatic) for moving operators or transmitting control signals. Most nuclear facilities only use pneumatic control systems and operators for nonsafety-related applications, as the control air is not usually an assured source during DBAs.

Electric. These damper operators are used whenever controls rely primarily on low voltage electric circuits to transmit control signals and are usually two-position. That is, they are either open or shut and cannot modulate. Most nuclear facilities use electric control systems and operators for safety-related applications because power can be obtained from the emergency electric power and control system.

Electrohydraulic. These damper operators are the same as the electric type described above, except they have the ability to modulate. Experience has shown that these operators require significant maintenance to keep them functional. They use an electric control signal to position a hydraulic system that, in turn, positions the damper.

5.3.2.4 Limit Switches

Limit switches are usually provided directly on the damper to detect the open and closed position of the damper blade. The switches are housed in enclosures defined by National Electrical Manufacturers Association, NEMA 250.[16] The contact rating must be properly selected for the electrical load. The force required to operate the limit switches must be considered to properly size the damper actuator.

5.3.3 Performance Requirements

The dampers for nuclear air cleaning systems must be designed to meet the following required performance requirements:

- Seat leakage,
- Frame leakage,
- Pressure drop,
- Closure (or opening) time, and
- Fire rating and closure.

Seat and frame leakage must be in accordance with ASME AG-1, Section DA,[1] for Leakage Class I (low leakage), II (moderate leakage), III (normal leakage), and IV (applications where leakage is of no consideration). Seat leakage class should be determined by the engineer based on radiological and health physics analysis and known or estimated airborne concentrations within the duct system. Frame leakage is also based on radiological assessments of the effect of airborne concentrations inside and outside the ductwork, as well as the system configuration. For further guidance on leak class determination, refer to ASME AG-1 Code, Section DA.[1]

Pressure drop of the damper has an important impact on proper system operation. Dampers with high-pressure drop, especially for counterbalanced pressure relief dampers, may restrict airflow and affect space pressurization. The pressure drop characteristics of dampers as a function of airflow rate or velocity indicates the ability of each particular type of damper to control airflow. Preferably, the pressure drop/airflow characteristic should be as close to linear as possible to achieve controllability. Opposed blade damper pressure drop characteristics make this type of damper well suited for flow or pressure control compared to parallel blade or butterfly dampers.

For fire dampers installed within duct systems where the airflow normally flows continuously and the damper must isolate portions of the duct system in case of fire, the damper must be designed for closure under airflow. This requirement has caused difficulties with past damper construction. Recent tests have shown that different manufacturers' dampers react differently based on their particular design. Some dampers are sensitive to air velocity, such as the shutoff dampers shown in **Figure 5.8**. **Figure 5.9** shows dampers with actuator options. These dampers are more sensitive to duct pressure upstream of the damper when they are closing.

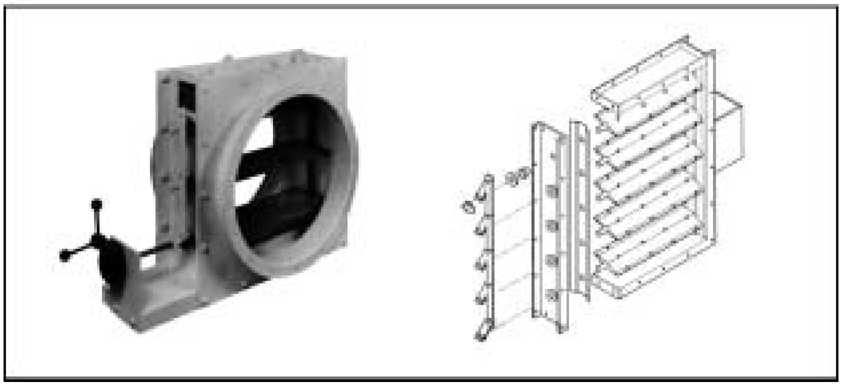


Figure 5.8 – Shutoff Dampers

5.3.4 Qualification Testing

Qualification consists of performing prototype or preproduction-model tests to verify the design, performance, and operational characteristics of the dampers. In the case of the Air Moving and Conditioning Association (AMCA)-rated dampers, these tests essentially consist of pressure drop and airflow determinations at various degrees of blade opening. The AMCA rating is generally considered sufficient evidence that suitable qualification tests have been performed. For dampers not listed by AMCA, the manufacturer should be required to provide performance data obtained under conditions equivalent to those used in the AMCA 500-D[15] test standard. One particularly important piece of information that can be obtained by qualification testing is the resistance of the fully open damper and the resistance versus blade-position curve from full open to full closed. Resistance must be included in the air cleaning system design calculations in the same manner as other system resistance. Qualification tests must be performed prior to fabrication and, if possible, prior to award of a contract.

Production units should be subjected to acceptance tests to verify that the units are in good operating condition and to document their ability to meet performance requirements such as leakage and closure time. Repetition of other qualification tests to demonstrate operational characteristics is generally unnecessary and unwarranted. Dampers should be cycled through the full range at least 10 times, with all accessories attached, to verify the free and correct operation of all parts and the correct adjustment, positioning, and seating of the blades. Maximum time for operation of any of the cycles should be not more than the specified cycle time. Limit switches, if used, should be checked for proper operation. Adjustments should be made as necessary during the test to correct deficiencies. Shop leakage tests for seat and frame leakage should be performed when applicable. Seat leakage testing should be performed after cycle testing is completed. Tests should be

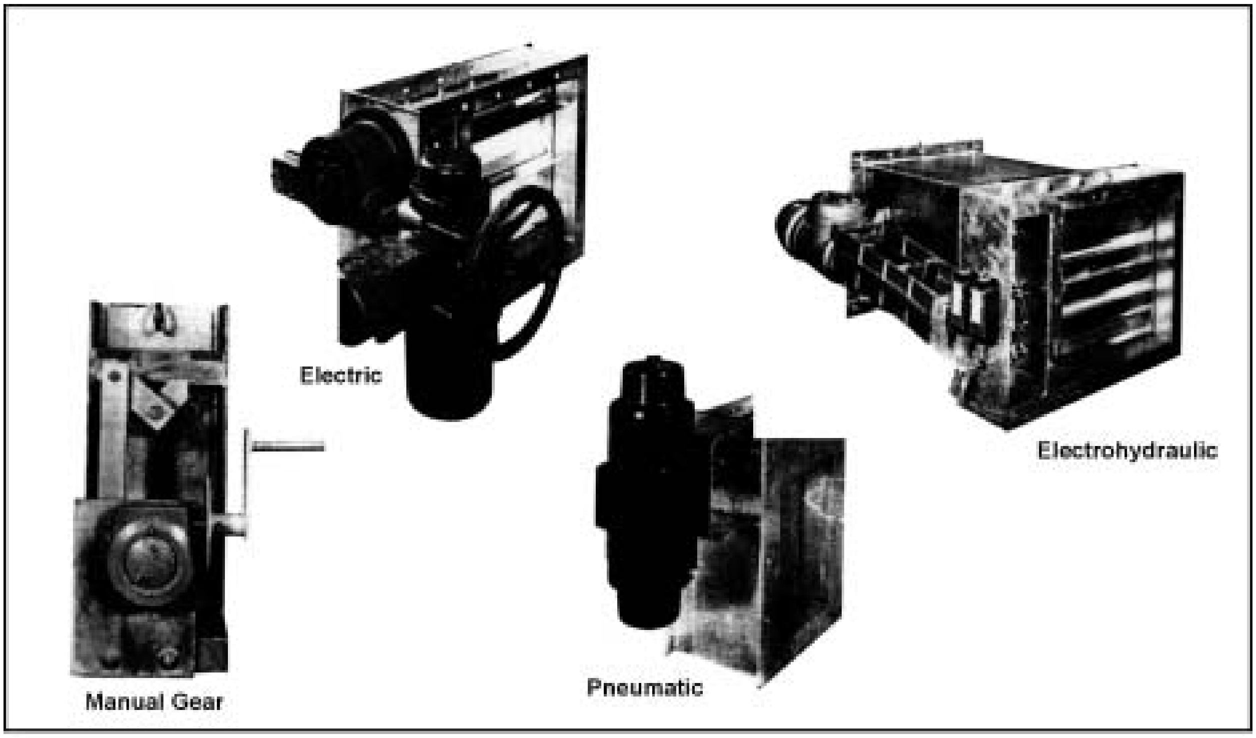


Figure 5.9 – Actuator Options

performed in accordance with ASME AG-1, Section DA[1]. Because damper operators are generally furnished to the damper manufacturer as a purchased item, a test to verify the torque characteristics of the operator is desirable after installation of the damper in its service position, particularly for control, shutoff, and isolation dampers for all safety-related dampers.

Fire dampers must be qualified for closure under airflow by testing in accordance with AMCA 500-D[15] for both plenum-mounted and duct-mounted configurations. The damper must close completely at maximum airflow rate for various sizes of dampers and for maximum static pressure. Fire and smoke dampers must be tested in accordance with UL-555[17] and UL-555S,[18] respectively, when dampers are required in fire- or smoke-rated barriers.

5.3.5 Louvers

The function of louvers is to keep rain, snow, and trash from being drawn into outside air intakes of air handling systems. They can be either fixed-blade or movable-blade design. The vast majority of louvers are of the fixed-blade type. If shutoff or modulation of the airstream is necessary, dampers can be used downstream of the louvers. If operable louvers are used and shutoff or modulation is required, then an operator is required (see Section 5.3.2). Architects usually are consulted when specifying louvers because the louvers are located on outside walls or roofs and should blend in with the architectural features of the structure.

It is important to account for the size of the area that the louver blades take up when sizing the louvers. Blades typically take up 50 percent or more of the free area that affects the velocity of the air entering the intake. The usual maximum velocity to prevent water and snow entrainment in the airstream is less than 500 fpm. Therefore, if 1000 cfm of air is being drawn into an intake and the louvers take up 50 percent of the free area, then the square footage of the opening required is:

$$1000\ \text{ft}^3/\text{min} \times 1/500\ \text{ft}/\text{min} \times 2 = 4.0\ \text{ft}^2 \text{ opening required}$$

In addition to the free area and velocity considerations, the pressure drop of the intake louvers must be included in the system pressure drop calculations.

For louvers on exhaust openings, the velocity is not usually a primary concern, with the exception that the higher the velocity, the higher the pressure drop that has to be accounted for in the system pressure drop calculations.

Finally, louvers must meet the same structural requirements as the rest of the air cleaning system. That is, they must meet the seismic loading requirements if they are required to function during and after a DBA. Louver testing must conform to AMCA 500-L.[15]

5.4 Fans and Motors

The selection of fans and motors for air treatment systems is a very important part of the design of the systems. An air cleaning unit may be properly designed and arranged, the duct system may be nearly leak-free, dampers may be properly constructed, and controls may be functioning correctly, but if the fan is not sized and selected properly, then the system will not perform its design function. For example, the system resistance must be correctly calculated, the effect of parallel or series fans must not result in surging, and the fan must be selected for the applicable range of airflow and pressure. ASME AG-1, Section BA,[1] contains a list of the design parameters necessary to properly specify and/or select a fan and motor.

For types of fans commonly used in air cleaning systems, refer to ASME AG-1.[1] Guidance on proper fan sizing, fan arrangement, connection to duct systems, leakage, mounting, and qualification testing is briefly discussed below. All of these factors must be considered when designing, selecting, and installing these fans. A synopsis of these factors and determinations are presented below. Actual determinations would require the use of the documents referenced.

5.4.1 Fan Types and Applications

Fan types can be classified as centrifugal, vaneaxial, and high-pressure blowers. Centrifugal fans can be further classified by blade type as airfoil, forward curve, radial, and backward inclined/backward curved. Vaneaxial fans can be classified as either fixed or adjustable pitch. All fans can be furnished as either direct or belt drive. Note that, for nuclear power plant applications, fans located inside the confinement are usually direct drive to minimize the maintenance and adjustments associated with belt drives (because confinement entry is limited).

High-pressure blowers may be required when airflow rates are low (10,000 cfm or less) and pressure is high (10 to 15 in.wg). This may dictate a radial-bladed centrifugal fan selection.

Vaneaxial fans are typically used in larger built-up systems when the fan is located as part of the duct system rather than part of the filter housing. Vaneaxial fans are best suited for airflow rates greater than 30,000 cfm and pressures less than 10 in.wg. Whenever possible, vaneaxial fans should be located downstream of filter units because the fan motor is in the airstream.

Fans should be selected such that fan power requirements are nonoverloading (i.e., the fan brake horse power does not increase with increasing airflow) unless provisions are made to prevent overloading the motor (e.g., airflow control and high limit trip). Radial-bladed and forward-curved centrifugal fan power increases with increasing airflow.

Belt drives should be used only in areas that are accessible for maintenance during normal and accident conditions. Multiple belts should be provided so that loss of one belt does not impair system function. For constant flow systems, variable pitch sheaves should be changed to fixed pitch sheaves after air balancing. Belt driven fans that must operate during and after dynamic events (e.g., seismic events) should be qualified for operation by testing.

Fans for general heating, ventilating, and air conditioning (HVAC) duty (e.g., air supply systems and small exhaust systems), are selected using the guidance for such systems found in sources such as the ASHRAE *HVAC Applications Handbook*,[19] the ASHRAE *Systems and Equipment Handbook*.[2] These systems can range in size from a few hundred cfm to over 100,000 cfm, and are usually low-pressure systems (less than 5 in.wg).

5.4.2 Fan Performance

5.4.2.1 Fan Sizing

Pressure Drop Determination

Much has been done in the HVAC industry to improve the analysis of system resistance. The ASHRAE *Handbook of Fundamentals*[3] has expanded what used to be one table of fitting loss coefficients to more than 30 pages of fitting data. ASHRAE discusses methods for designing industrial exhaust systems and balancing branch duct resistance either by utilizing balancing dampers or by sizing ductwork. For systems handling highly radioactive particulate, self-balancing is recommended to eliminate particulate accumulation in the duct system. This recommendation must be considered against the potential for changes to duct runs during installation.

Use of the calculation method presented in the ASHRAE *Handbook of Fundamentals*,[3] Chapter 34, is recommended to determine fan pressure requirements. Acceptable methods are equal friction, static regain, and T-Method optimization. A total pressure grade line, summarizing the branch and main duct pressure drop, should be prepared for each fan system to analyze the system total pressure at various points. This grade line is also useful for reviewing or establishing the duct design (static) pressure (total pressure – velocity pressure in duct fitting).

If the fitting design does not match one of those in Chapter 34 of the ASHRAE *Handbook of Fundamentals*,[3] another useful reference is the ASHRAE *Duct Fitting Database*.[20] This is an interactive computer file on a 3.5-inch diskette containing loss coefficient tables for 228 fittings.

Sufficient margin should be included to cover the potential field modifications that may be necessary during initial installation, as well as any modifications that may be necessary throughout the life of the facility (see the following section on "System Effect Factors").

Equipment (coils, dampers, filters, air diffusion equipment, etc.) resistance must be included in the pressure drop calculations. Whenever possible, calculations should be based on actual purchased equipment and, where possible, tested components. Preliminary calculations should be prepared with estimated pressure drop values and updated with final values.

System Effect Factors

The inability of fans to perform in the field in accordance with published ratings has long troubled the industry. This problem arises partly because the ratings are based on idealized laboratory conditions that are rarely encountered in the field, and partly because of design and/or field compromises that are made to accommodate the field situation. Many fan operation problems stem from poorly designed connections to the duct. Close-coupling, "too short" transitions between unmatched (in size) duct and fan inlets, square-to-round connections, and poorly designed inlet boxes create a vertical or eccentric flow into the fan impeller, resulting in noise, vibration, and reduced efficiency. A 45-degree spin in the direction opposite fan rotation can reduce fan delivery by as much as 25 percent and require a compensating increase in fan pressure of 50 to 55 percent. **Figure 5.10** shows the effects of various inlet conditions on fan performance and the resulting increase in fan capability (fan static pressure) to compensate for these effects. Too often, these effects are not considered when calculating fan requirements, with the result that neither the fan nor the filters can perform to the desired design levels. Outlet connections also affect fan performance, as indicated in **Figure 5.11**.

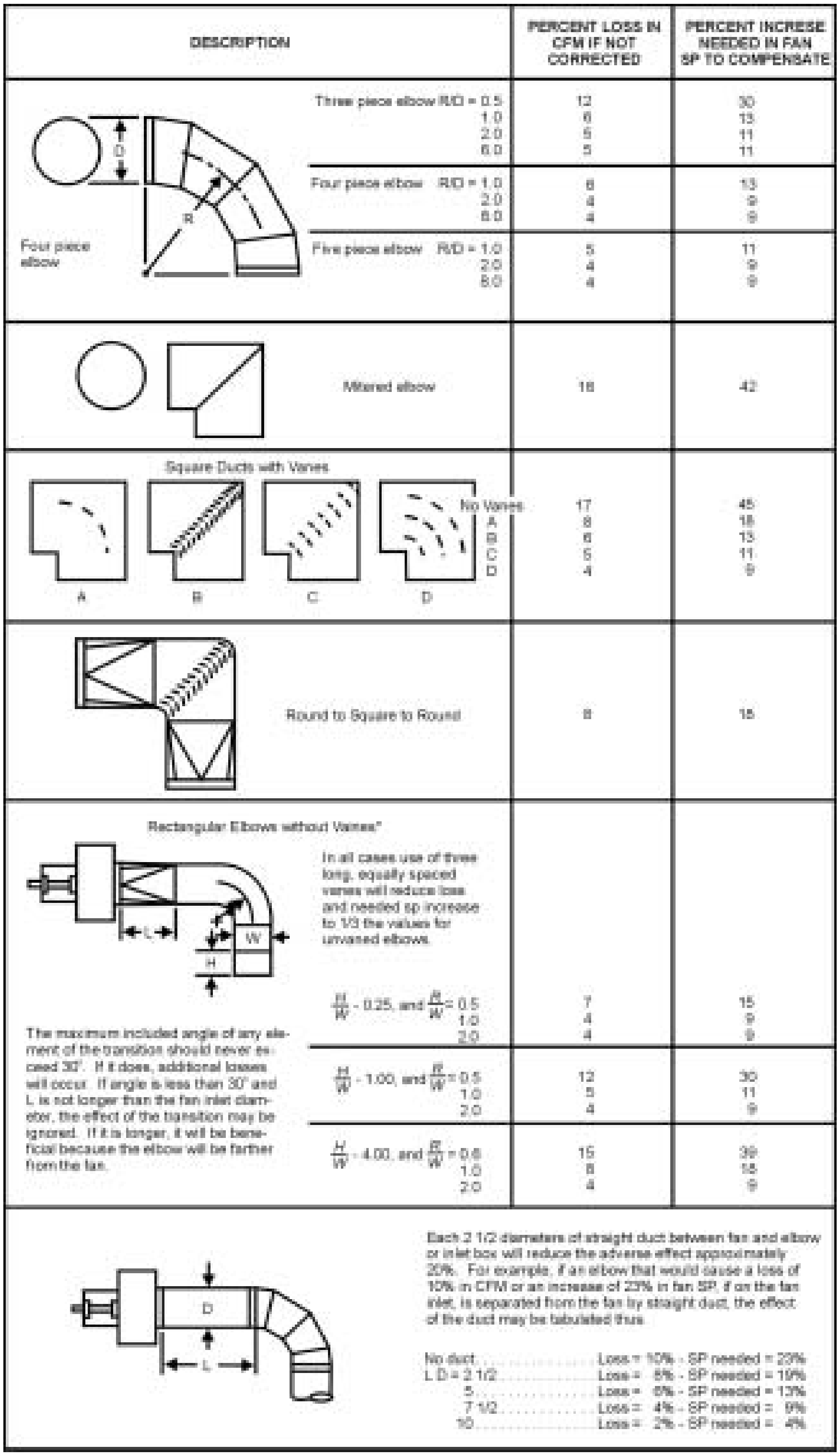
Note: For further details about system effects curves, refer to AMCA, *Fans and Systems,* 1990, AMCA 201[21] or the fan manufacturers' data. It is extremely important that the system effects be considered for any enclosed fan. Fan performance published in catalogues is based on free-standing test data that does not consider system effects and cannot be considered for system performance.

To alleviate the situation, AMCA has published a *Fan Application Manual*,[22] Part 2 of which includes a set of "system effect curves" which the designer can use to predict the effects of design features (such as the inlet and outlet conditions illustrated in Figure 5.11) on fan performance and, when needed, to allow for them in initial fan selection. System effects are the losses in fan performance that result from the fan being installed in a less than ideal configuration. These effects must be considered by the designer to obtain a realistic estimate of fan performance under "real life" conditions. **Figure 5.12** illustrates a deficient fan-system interaction resulting from one or more undesirable design conditions. It is assumed that pressure losses in the duct system were accurately estimated (point 1, curve A), and a suitable fan, based on published ratings, was selected for operation at that point. However, no allowance was made for the effect of the fan connections on fan performance (i.e., the interaction between the fan and the system as designed). To compensate for the system effect (capacity loss resulting from unfavorable interaction between the fan and its connections), a system effect factor must be added to the calculated system pressure losses to determine the actual system characteristic curve. It will then be possible to select the fan required to produce the required operating characteristics.

Testing to establish the capability of the fan in a nuclear air cleaning system, as originally installed, is recommended by ASME AG-1, Section TA.[1] Part 4 of the AMCA *Fan Application Manual* [22] provides guidelines for such testing, including examples of the application of system effect factors for various system configurations. Planes of measurement, measurements to be made, average test readings, calculation of test results, and corrections to overcome deficiencies disclosed by the tests are all covered in detail. It is preferable to apply such system effect factors before selection, purchase, and installation of a fan to prevent the incorporation of unfavorable features into the system design. In applying system effect factors, it must be recognized that those factors given in the AMCA manual are only guidelines and general approximations, although many have been obtained from research studies. Fans of different types and fans of the same type that are made by different manufacturers will not necessarily interact with the system in exactly the same way. It is necessary, therefore, to apply judgment based on experience using system effect factors.

5.4.2.2 Fan and System Curves

A major requirement for a fan operating in a high-efficiency air cleaning system is its ability to perform safely and efficiently over a much larger variation of resistance than more conventional ventilation systems. This variation of resistance is caused by dust loading of the HEPA filters and may double from the time of filter installation to the time of filter change, or may increase as much as five times in some systems (see the discussion of particulate filter change frequency in Chapter 2). The increase in resistance across the HEPA filters is usually the major factor influencing the pressure flow relationships of high-efficiency air cleaning systems. Fan performance (airflow versus pressure capability) and system resistance versus airflow are represented by characteristic curves such as curves A, B, and C of Figure 5.12. The volume of air that can be delivered by the fan is determined by the intersection of the fan and system characteristic curves. The flow represented by this point of intersection is the only flow that can be delivered by the fan under the given operating conditions. In most cases, a fan with a steeply rising characteristic (curve A, Figure 5.12) is



DESCRIPTION	PERCENT LOSS IN CFM IF NOT CORRECTED	PERCENT INCRESE NEEDED IN FAN SP TO COMPENSATE
Three piece elbow R/D = 0.5	12	30
1.0	6	13
2.0	5	11
6.0	5	11
Four piece elbow R/D = 1.0	6	13
2.0	4	9
6.0	4	9
Five piece elbow R/D = 1.0	5	11
2.0	4	9
6.0	4	9
Mitered elbow	16	42
Square Ducts with Vanes: No Vanes	17	45
A	8	18
B	6	13
C	5	11
D	4	9
Round to Square to Round	8	18
Rectangular Elbows without Vanes* — In all cases use of three long, equally spaced vanes will reduce loss and needed sp increase to 1/3 the values for unvaned elbows.		
$\frac{H}{W}$ - 0.25, and $\frac{R}{W}$ = 0.5	7	15
1.0	4	9
2.0	4	9
$\frac{H}{W}$ - 1.00, and $\frac{R}{W}$ = 0.5	12	30
1.0	5	11
2.0	4	9
$\frac{H}{W}$ - 4.00, and $\frac{R}{W}$ = 0.5	15	39
1.0	8	18
2.0	4	9

The maximum included angle of any element of the transition should never exceed 30°. If it does, additional losses will occur. If angle is less than 30° and L is not longer than the fan inlet diameter, the effect of the transition may be ignored. If it is longer, it will be beneficial because the elbow will be farther from the fan.

Each 2 1/2 diameters of straight duct between fan and elbow or inlet box will reduce the adverse effect approximately 20%. For example, if an elbow that would cause a loss of 10% in CFM or an increase of 23% in fan SP, if on the fan inlet, is separated from the fan by straight duct, the effect of the duct may be tabulated thus.

No duct.................Loss = 10% - SP needed = 23%
L D = 2 1/2.............Loss = 8% - SP needed = 19%
5.......................Loss = 6% - SP needed = 13%
7 1/2...................Loss = 4% - SP needed = 9%
10......................Loss = 2% - SP needed = 4%

Figure 5.10 – Effect of Fan Inlet on Performance

desirable to maintain reasonably constant airflow in the system over the entire life of the HEPA filters. If a fan with a broad, flat characteristic is chosen, it will be less capable of delivering the required airflow as the filters become dust-loaded (curve 1 to curve 2), and either system performance (i.e., airflow) or filter life will

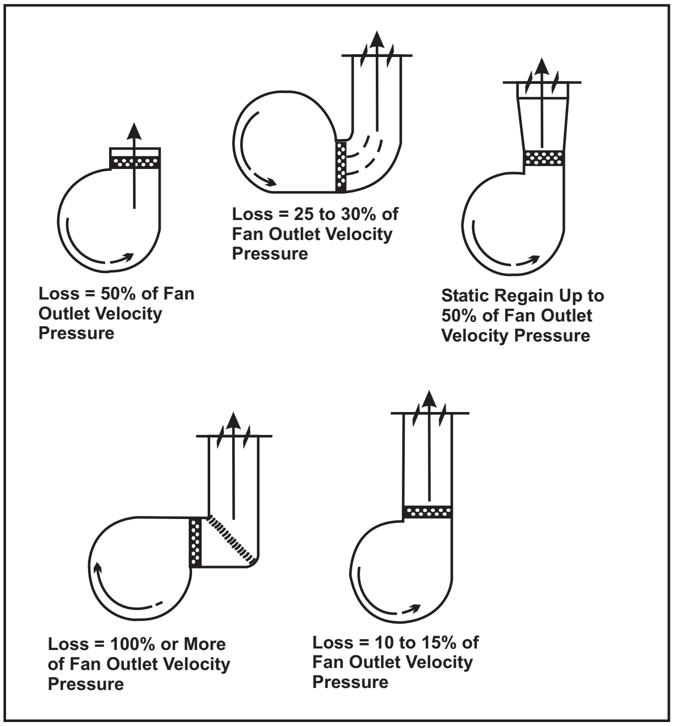


Figure 5.11 – Effect of Fan Outlet Connection on Fan Performance

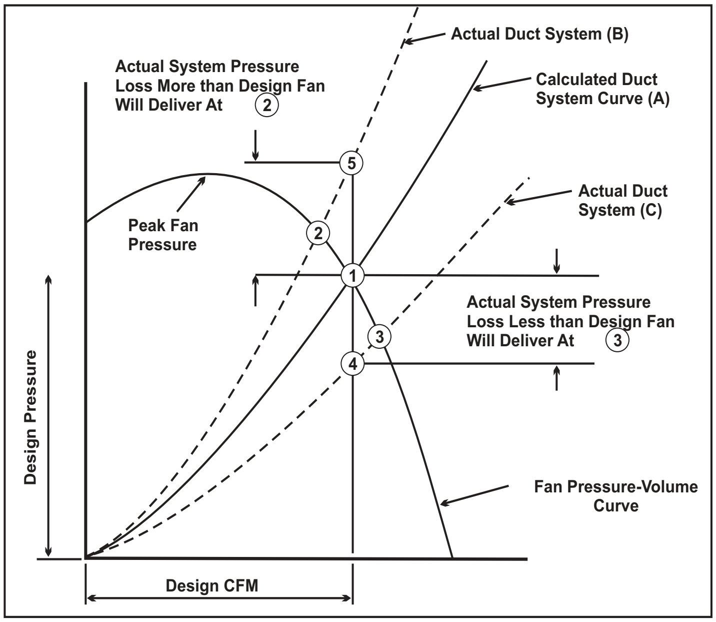


Figure 5.12 – Duct System Curve Not at Design Point

have to be sacrificed. Any decrease in filter life will, of course, be accompanied by higher change frequency and corresponding increases in operating and maintenance costs. If a pressure-equalizing device (damper) is installed to balance system pressure against filter pressure drop in order to maintain a constant pressure-airflow relationship in the system, a penalty in operating (power) costs will result.

5.4.2.3 Fan Leakage

Flexible Connection Leakage

Vibration created by fans, motors, and drives can be isolated by using flexible connections between the fan and ductwork on both the fan discharge and suction. Where such connections are used, a frequent problem has been tearing and pulling-out of the fabric (from which the flexible connection is made) at the connector clamp and an associated increase in leakage. The flexible connection design shown in **Figure 5.13** can overcome these problems. The fabric shown consists of two layers of 30-ounce neoprene-impregnated fiberglass cloth, lapped so that the ends are displaced from one another, and glued. Flexible materials reinforced with fiberglass or other products are also available. Flexible connections should be periodically inspected (visually) to ensure the connection is intact (no tears or holes). Eliminating leakage at the flexible connection is important to the effective operation of the unit. With the fan located properly with respect to the contamination concentration, the leakage on the suction side should not impact personnel dose, but could impact system effectiveness by reducing the flow rate of the discharge leakage through the connection at the point of contamination. This could affect the local derived air concentration (DAC) levels, depending on the relative concentration between the space and the duct.

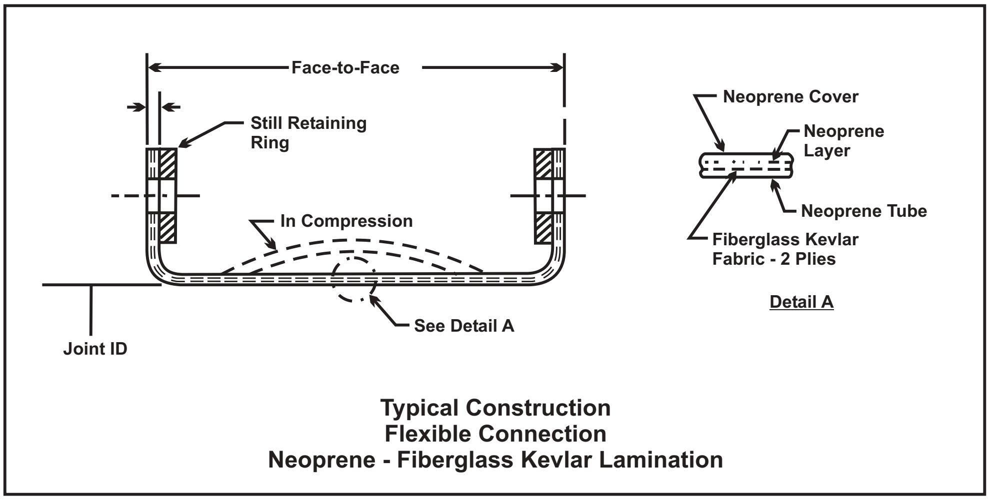


Figure 5.13 – Flexible Connection Design

Flexible connections should be qualified for the temperature, pressure, RH, and contaminants that will be encountered. However, since the flexible connections are exposed to continuous stresses due to airflow turbulence and fan vibration, the flex connections should be replaced frequently throughout the life of the plant. A maintenance frequency should be planned based on the results of the periodic surveillance inspections for each specific fan.

Shaft Leakage

Fan shaft penetration of fan housings should be designed to minimize leakage. When the fan is located properly so that leakage does not impose a contamination burden on the space, or the fan is located in the space supplied by air from the fan, then no special sealing is required. However, if there is a potential for a significant increase of DAC levels or a significant impact on airflow rate from the space the air is being induced from, then shaft seals should be installed. Shaft seals should limit leakage to 0.01 percent of design airflow rate per inch of fan operating pressure or 0.5 cfm, whichever is greater.[1] The safety analyses should be consulted for allowable leakage for safety class designs, especially for systems with multiple HEPA filter banks. If the fans are located downstream of the HEPA banks, or if in a potentially contaminated area, extremely small levels of fan shaft in-leakage (< 0.001 cfm) may be unacceptable for maintaining the desired level of removal.

Fan Housing Package

Fan housings should be specified to be leaktight, including all penetrations and access doors. Access doors should be bolted and gasketed.

5.4.2.4 Fan Arrangement

Fan Location

The location of the fan in the system relative to the filter housing is an important consideration in minimizing the effect of system leakage. Fans in contaminated exhaust systems installed immediately downstream of the filter housing and as close to the exhaust stack as possible place most of the system under negative pressure. Leakage is into the system, thus ensuring greater personnel dose protection. In addition, the fan handles cleaner air, thus reducing maintenance personnel dose during fan repair or overhaul.

For habitability systems with the filter housing located outside the protected space, the fan should be located on the upstream side of the filters. This eliminates system in-leakage that could bypass the filters.

Fans have been located within the filter housing to reduce noise transmission and, more importantly, shaft leakage concerns. However, adequate space must be provided for air inlet conditions. Further information is covered in Section 5.4.2.3, "Fan Leakage."

Multiple Fan Installation

Installation of two fans in series is sometimes desirable where a steeply rising pressure-airflow characteristic is needed. However, caution must be exercised in such a design. In theory, the combined pressure-volume characteristic of two fans operating in series is obtained by adding the fan pressures at the same volumetric airflow, as shown in **Figure 5.14**. Care must be taken in designing the connection between the fans, because a significant loss of efficiency can occur in the second-stage fan due to nonuniform airflow into its inlet, particularly if the two fans are closely coupled. Manufacturers may be able to install two fan wheels in series within a single housing, which is longer than a single-wheel fan. Fan manufacturers should provide certified fan performance curves for these multistage fans.

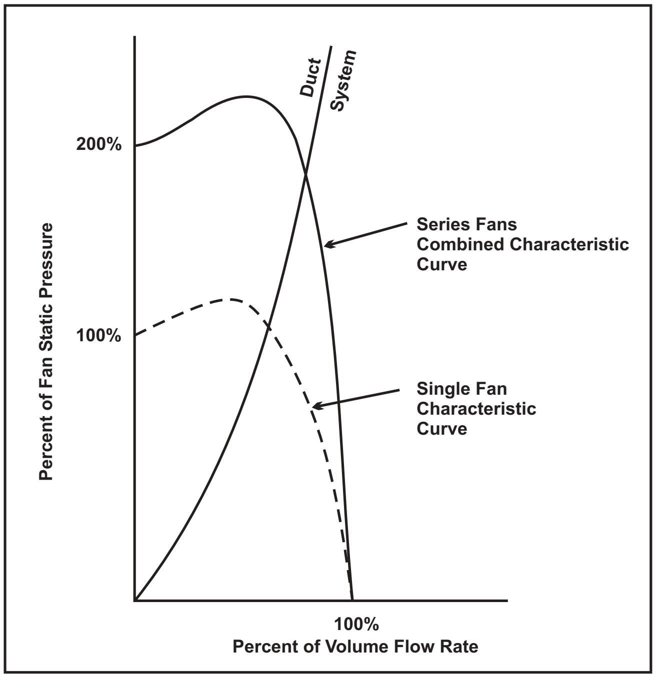


Figure 5.14 – Typical Characteristic Curve of Two Fans Operating in Series

For fans installed in series and not in a common plenum, a bypass duct is recommended so that a failed fan can be isolated from the system for repair and to avoid additional system resistance due to the failed fan wheel. Two or more fans are often operated in parallel to move large volumes of air, to enhance the control of segmented air cleaning facilities, or to limit the installed capacity (i.e., filters, adsorbers) of any one unit of the air cleaning system. The combined volume-pressure curve in this case is obtained by adding the volumetric capacity of each fan at the same pressure (**Figure 5.15**).

One concern in parallel fan installations is that some fans have a positive slope in their characteristic curves to the left of the peak pressure point (Figure 5.15). If the fans are operated in the pressure-volume regime of this positive slope, unstable operation may result. This is shown by the closed loop to the left of the peak pressure point in Figure 5.15 (this loop is obtained by plotting all of the possible combinations of flow at each pressure). If the system's characteristic curve intersects the fan characteristic in the area of this loop, more than one point of operation is possible; this may cause one of the fans to handle more of the system airflow than the other and result in a motor overload. The unbalanced flow conditions tend to shift rapidly so that the fans intermittently load and unload. The pulsing that results from such loading and unloading generates noise and vibration and may cause damage to the fans, motors, and ductwork. In addition, if more than two fans are operated in parallel, the designer and/or fan manufacturer should review the fan performance curves and system curves for possible combinations of fans, assuming one or more are out of operation for maintenance, filter change-out, or repair. Fans should be selected for stable flow throughout the service conditions (clean to dirty filter pressure drop) and combinations of fans.

Mounting

Proper mounting of the fan will minimize noise and vibration, and reduce maintenance costs. Noise is objectionable in supply and exhaust systems, and is often difficult and costly to eliminate after the system goes into service. Excessive noise in exhausts and air cleanup systems is often accompanied by vibration and pulsation. These conditions may be harmful to filters, adsorbers, and other components. Flutter of HEPA filter separators, for example, is a common cause of filter failure, and vibration of activated-carbon-filled adsorbers can result in settling and crushing of the granules and, eventually, carbon loss that can cause bypassing of contaminated air.

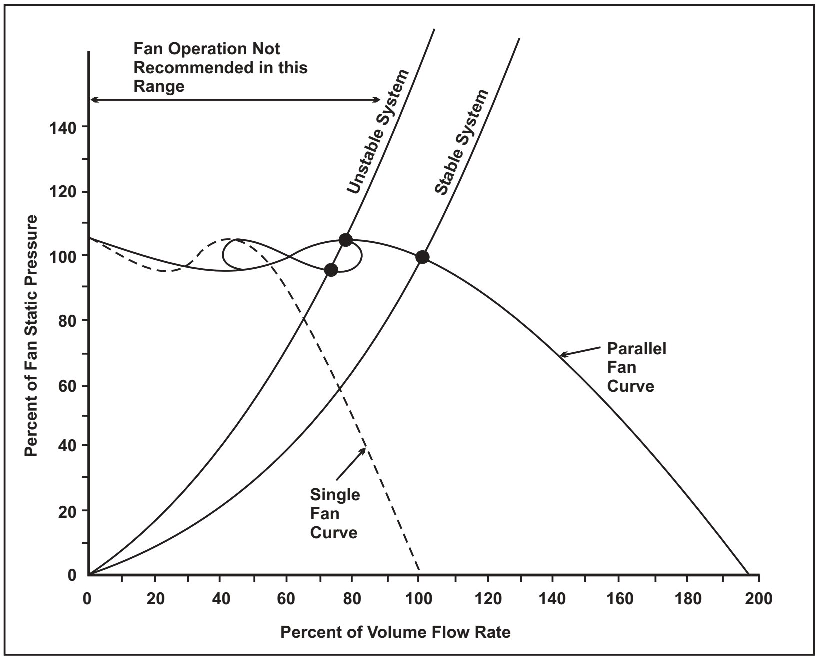


Figure 5.15 – Parallel Fan Operation

When practicable, mounting of the fan and motor on a common base designed for isolation of vibration is recommended. The fan and motor are mounted on a concrete base that acts as an inertial pad to limit the amplitude of vibration and to dissipate vibrational energy. The pad is mounted on spring isolators, which will provide a high degree (99 percent or more) of vibrational damping. For some systems, positive amplitude limiters may be required to restrain the base from excessive movement under extreme conditions (such as the accelerations imposed by a DBE). Some designers require hard-mounting of fans where seismic requirements and continued operation during and after an earthquake must be considered. Infiltration may be reduced by designing a tighter building structure. Careful balancing of the fan shaft and impeller to minimize vibrations that cannot be isolated via installation design is particularly important in this latter design.

Building Pressure Effects

Sizing of supply and exhaust fans must recognize the interaction of these fans with each other in order for nuclear air-cleaning systems to maintain proper space pressure relative to surrounding areas. See Section 2.4.1 of this Handbook for additional information concerning these interactions.

In push-pull systems (i.e., systems containing both supply and exhaust fans that operate at the same time), the space pressure depends on the relative capacity of the fans. If supply flow exceeds exhaust, the space is positive. If exhaust exceeds supply, the space pressure will be negative. When space pressure is required to be negative, the exhaust fan capacity should compensate for infiltration, pressure surges, wind effects (i.e., pressure variations in the building and ductwork due to variable wind conditions exterior to the building), as well as temperature variations between supply and exhaust air, to eliminate any possibility of over pressurizing the building via the supply fans. The pressure effects of other building ventilation systems serving adjacent spaces should also be considered.

Improper fan operation can be avoided by carefully evaluating system pressure drops and interactions under all predictable operating conditions, and by specifying the type and size of fan that matches the demands of the duct system as installed. Control must be exercised over the installation of ducts and fans to prevent field compromises that can reduce the ability of the system to perform as intended.

5.4.2.5 Fan Construction

AMCA has developed standards for fan construction. In general, these standards are applicable to the construction of fans for nuclear air cleaning systems. In addition, fans for nuclear air cleaning systems should be constructed in accordance with ASME AG-1, Section BA,[1] which defines additional specific features that are required for nuclear applications.

5.4.2.6 Qualification and Testing

Fans for nuclear air cleaning systems should be qualified, rated, and tested for the following:

- Performance,
- Structural capability,
- Vibration,
- Sound,
- Leakage, and
- Environmental conditions.

ASME AG-1 Code, Section BA,[1] provides inspection and testing requirements for fans and motors. AMCA 210[23] defines the methods for testing fans for rating purposes. Environmental qualification and testing of electrical components should be in accordance with IEEE-323.[24]

Standard motor tests that include “First Unit of A Design” and “Routine Motor Tests” (all motors) should be performed in accordance with IEEE 112[25] and ASME AG-1, Section BA.[1] Documentation of test results should be prepared in accordance with the above references.

5.4.2.7 Fan Reliability and Maintenance

Operational reliability is an important consideration in selecting fans for nuclear applications. Even when the system is planned for part-time or intermittent operation, continuous operation may be required after the system goes into service. This should be a consideration in the design and procurement process.

Adequate access for maintenance and service is imperative, and fans installed above floor level must have sufficient clear space around and below for personnel to get to them with the aid of ladders and/or scaffolding. Permanently installed ladders and galleries are recommended to ensure ease of access for maintenance and repair.

Procedures should be developed for periodic, preventative maintenance based on the fan manufacturer’s recommendations and actual field operational experience. These procedures are critical for the reliability of the fan and its operational readiness in the event of a DBA.

5.4.2.8 Special Duty Considerations

Temperature, Pressure, and Humidity

Fans are constant-volume machines whose airflow rate can be impacted by variables such as temperature, pressure, and RH because they affect the mass flow rate of air being moved. It is necessary to identify and specify these variables for both normal and accident conditions so the fan manufacturer can make proper fan and drive selections. In addition, temperature, pressure, and humidity can affect fan components such as the bearings and bearing lubricant. Therefore, the fan manufacturer must know these properties to make proper material selections for fan components.

Material Moving

Fans that are required to move particulate matter require identification and specification of the properties of the airstream. Particulates can be abrasive, require high transport velocities, or be composed of corrosive, explosive chemicals. These materials can affect the fan wheel, casing, shaft, bearings, bearing lubricant, etc., and the fan manufacturer must know these properties to make the proper material selections for the fan components.

Contaminated Air Moving

Fans that are required to move contaminated air (primarily radioactive particles in nuclear facilities) also need to have these properties identified and specified. Radioactive contaminants can affect some of the materials used in fan construction (primarily bearing lubricants) or in ductwork components that are attached to the fan (flexible connections and gaskets). Another primary concern is contaminated leakage into or out of the fan (see Section 5.4.2.3 for information concerning leakage). The fan manufacturer must know the properties of the contaminated air so that proper material selections and leakage provisions can be provided.

5.5 Air Intakes and Stacks

5.5.1 Locating Intakes and Stacks

The design and location of exhaust stacks and air intakes have an important bearing on system performance. If air intakes are too close to the ground, blowing sand, dust, grass clippings, and other particulate matter may be drawn into the building, plugging the supply-air filters and/or reducing their life. Exhaust fumes from vehicles passing nearby or standing close to the building may also be drawn into the building. Intakes must be sited to protect them from snow, ice, and freezing rain during the winter, and baffles or louvers must be provided to give protection from driving rain and to minimize the effect of wind. Architectural louvers should be designed and tested in accordance with AMCA 500-L[15] for pressure drop and water penetration (see Section 5.3.5 for additional information concerning louvers). Wind pressure can have an appreciable effect on flow rates in a low-head ventilation system and can cause pulsations that may disrupt or reverse differential pressure conditions between the zones of the building.

Average wind direction and weather conditions that are likely to cause stack discharges to areas close to the ground (known as looping and fumigation) must be analyzed when establishing the location of stacks and intakes. This analysis is necessary to ensure that stack effluents cannot be drawn back into the building or into an adjacent building. Intakes should be located upwind of stacks (i.e., based on the prevailing wind for the site). Intakes downwind of shipping docks may be prone to drawing vehicle exhaust fumes into the building. Intakes located close to a roof or in a roof penthouse may have the same problems as those located too close to the ground.

Considerable guidance on the location of intakes and exhaust stacks is given in Chapter 16 (“Airflow Around Buildings”*)* of the 2001 ASHRAE *Handbook of Fundamentals.*[3] The flow around adjacent structures is complex and is affected not only by a building’s dimensions, but also by the topography surrounding a building. Proper consideration should be taken regarding the wind and stack flow patterns for a single rectangular building. Air intakes located within the recirculation zone or contaminated region will re-entrain the effluent. Computational fluid dynamics models could be developed to determine flow patterns around the building.

Intakes located on the sides of buildings may also be affected by the pressure (positive or negative) at those points. Ventilation systems should be designed and sized to account for this pressure, especially if a negative pressure is possible for a supply system or a positive pressure may exist for an exhaust system. A static pressure at least equivalent to the surface pressure associated with the design wind velocity for the specific location should be included in system pressure calculations. Pressure controls (described in Section 5.6.4) also should be used to regulate flow fluctuations occurring due to the wind velocity and surface pressure.

In northern climates, intakes should be designed to minimize snow entrainment. Even at low velocity through louvers, snowflakes can enter and clog prefilters located close to the louvers. In addition, hoarfrost can form on operable louvers and prevent their operation. Hoarfrost can also block louver screens. To prevent such potential problems, it may be advisable to heat the areas adjacent to the louvers. If snow is blown or otherwise induced into the ventilation system and no provision is made for settling or dropping out snow or ice particles, the filters can become clogged.

To reduce the potential for this problem, whenever possible, intakes should not be located on the windward side of buildings. Consideration should be given to modeling flow around buildings and intake structure designs if snow entrainment is causing operating problems that do not have conventional solutions.

The following factors should be considered when locating stacks:[19]

- High stack velocity is a poor substitute for proper stack location. A stack velocity to wind velocity ratio of 4:1 is required to discharge effluent out of the recirculation cavity boundary for a stack located flush to a roof.
- If an enclosure is needed around the stack, the stack should extend above the building zone of the enclosure and should not be flush to the enclosure.
- A circular stack shape is recommended. Nozzles may be used at the tip of the stack to increase exit velocity.
- Stack caps that deflect effluent downward are not recommended. High exit velocities will prevent rain from entering. Some drainage provision is recommended instead of rain caps.
- For both stacks and intakes, provision should be made for drainage of water or melted snow that may be induced into the system.
- Stacks should be located where they cannot damage the facility they serve or other important nearby structures.

5.5.2 Sizing Intakes and Stacks

Air intakes should be sized to minimize pressure drop and maintain air velocity through the free area below the velocity at which water droplets may be entrained (usually less than 500 fpm). Manufacturers should be requested to provide pressure drop and water penetration test results for louvers tested in accordance with AMCA 500-L.[15]

Sizing of stacks is even more important to prevent re-entrainment and ensure proper dispersion. Dispersion calculations should be performed to determine whether elevated, ground-level or mixed mode effluent release is required to maintain offsite personnel exposures within the plant environmental permit, Technical Safety Requirements, and applicable Federal, State, and local regulations. The term “elevated release” typically refers to stacks that are situated well above the tallest building. Ground level releases are typically exhaust points located on the building wall or roof. "Mixed mode" refers to stacks that are marginally higher than the tallest building. In each case, location of the stack should be based on the factors discussed in Section 5.5.1. When calculating pressure drop tornado and other missile barrier needs, the need to prevent access by unauthorized personnel should be considered. For further guidance, see Section 5.5.3 and 5.7.1.

The exit velocity of the stack should be at least 1.5 times the wind velocity to minimize downwash. Stacks may need to be partitioned or sectioned if multiple systems discharge into the stack and individual system operations do not occur at the same time or frequency. A minimum stack exit velocity of 3,000 fpm is recommended to prevent downwash from winds up to 22 miles per hour (mph), to keep rain out, and to prevent condensation from draining down the stack. If condensation may be corrosive, a stack velocity of 1,000 fpm is recommended with a drain at the bottom to remove condensation and a nozzle at the top of the stack to maintain high exit velocity. High exit velocity from a stack, however, does not remove the need for a tall stack.

5.5.3 Structural Design Aspects

Louvers designed for conventional ventilation and air conditioning applications are usually acceptable for use as air intakes for nuclear air cleaning systems. If louvers are required to remain in place following DBAs (such as earthquake or tornado), they should be designed in accordance with the requirements of ASME AG-1, Section DA.[1]

Stacks should be designed in accordance with the requirements of ASME AG-1, Section AA,[1] and ASME STS-1-2000, *Steel Stacks.*[26] Loading due to design wind, tornado, hurricane, and other abnormal meteorological conditions should be included in the structural analysis, as well as dynamic loads due to seismic excitation whenever applicable. Even if not required to remain functional, stacks should be designed so they do not collapse and cause unacceptable damage to surrounding structures, systems, or components. Stiffeners for stacks should be located on the outside to avoid providing ledges for potential "buildup" of radioactive material, even though the air has been "cleaned." The structural design of stacks should be qualified by analysis in accordance with AG-1, Section AA.[1] Care should also be exercised in the structural design so that stacks do not "crimp" or bend and cut off the effluent flow if they are subject to a strike by high wind- or tornado-generated missiles.

Openings in nuclear-safety-related structures for either air intakes or exhaust stacks should be protected from the effects of high wind or tornado missiles if such a missile could damage a nuclear-safety-related component and prevent it from functioning. Missile protection typically involves utilizing staggered building wall structures or a lattice of steel bars to prevent a straight-through missile path. Sufficient space must be allocated for these intake structures. Free-area reduction caused by the use of the staggered walls or steel bars in the openings must be considered when sizing the openings, particularly intakes, so that velocity requirements are not exceeded. For security needs at air inlets, see Section 5.7.1.

For metal exhaust ducts, see the American Conference of Governmental Hygienists, *Industrial Ventilation, A Manual of Recommended Practice,* Chapter 5, "Exhaust System Design Procedure."[4]

5.6 Instrumentation and Control

5.6.1 Codes and Standards Requirements

Instrumentation and control systems, components, and equipment should meet the requirements of ASME AG-1, Section IA.[1] In addition, they should be qualified according to the requirements of IEEE 336,[27] 383,[28] and 384.[29]

5.6.2 Functional Requirements

The function of the instrumentation and control systems associated with nuclear ventilation and nuclear air cleaning systems is to control the environment of the space served within the limits of the controlled variable and to monitor the performance of the system and its components to ensure safe, efficient, reliable operation. The design of instrumentation and control systems should consider the consequences of single failure as well as environmental conditions.

The primary variables by which nuclear air cleaning systems are controlled are temperature, airflow rate, and pressure. Temperature, pressure, flow, and radioactivity levels are monitored to indicate system performance and alarm abnormal conditions.

Effluent air cleaning systems typically are controlled to maintain a minimum negative pressure or building pressure around a preselected flow rate. Habitability systems are usually controlled to maintain a constant airflow rate that is selected to maintain a positive pressure in the space served. Temperature is also usually controlled for habitability systems.

Instrumentation should be provided to monitor the radioactivity levels of effluent discharged into the atmosphere. Each discharge point that could potentially have concentrations exceeding Technical Safety Requirements limits should be monitored. Monitoring of emission airflow rates and concentrations is also required. Values in excess of established high limits should be alarmed in the control room. In addition, airflow rates and radioactivity levels for habitability systems should be monitored and alarmed.

The best indicator of system performance for continually operating systems is the level of radioactivity. Monitoring flow rates and concentrations both before and after air cleaning units could indicate trends in filter degradation. The controls recommended in ASME AG-1, Section IA,[1] should be provided to assist the operators in monitoring system performance.

5.6.3 Airflow Control

Airflow control is one of the most important control variables for nuclear air cleaning systems. Nuclear air cleaning system pressure could vary by as much as 25 to 30 percent, depending on system components, clean filter pressure drop, and the change-out pressure drop**.** It is recommended that airflow rates be maintained within ±10 percent of design to maintain proper fan performance. The airflow rate is usually required to be automatically controlled by: (1) discharge or inlet control dampers, (2) variable inlet vanes, or (3) variable speed control.

To control the airflow rate, the flow first must be accurately measured. Flow should be measured where the air velocity profile is uniform. AMCA 210[23] and 203,[22] as well as ACGIH *Industrial Ventilation*[4] provide guidance on the proper location of airflow sensing devices. Several manufacturers produce airflow measuring devices that can provide accurate averaged velocity pressures, as well as the instrumentation to convert velocity pressures to airflow rates.

An alternative method of controlling the airflow rate within ±10 percent of design is to select a fan that has a steep performance curve such that a 25 percent change in pressure will not result in more than a 10 percent change in flow rate. This is difficult to achieve, however, due to system margins, system effect factors, and the ability to accurately calculate system pressures.

The choice of control dampers or inlet vanes will depend on fan type, required pressure reduction, and airflow uniformity. Control dampers must be sized to provide controllability. Flow stability must be maintained to avoid a controller "hunting" (i.e., control instability).

If the pressure reduction required is 40 percent or more of the fan static pressure at the operating point, inlet vane control may be desirable. An inlet vane control damper costs about three times more than equivalent parallel-blade or opposed blade dampers but, at a capacity reduction of 50 percent or less, it produces power savings that can average 25 percent compared to parallel-blade or opposed blade control dampers. Another factor that favors the inlet vane damper over a control damper in the duct is that it permits operation of the fan for long periods at reduced load. Full-open inlet vane dampers cause the fan to operate at some penalty to airflow, static pressure, and horsepower.

AMCA 210[23] recommends the use of variable vane inlet dampers when the fan is to be operated for long periods at reduced flow. The effectiveness of this damper stems from the fact that the inlet vanes generate a forced inlet vortex that rotates in the same direction as the fan impeller; similarly, any restriction of the fan inlet reduces the fan performance. Inlet vane dampers are of two types: integral (built-in) and add-on. The resistance and system effect of inlet vane dampers in the wide-open position must be considered in the original fan selection and system functional design. System effects of inlet vane dampers should be available from the fan manufacturer; if not, the system effect curves of AMCA 210[23] should be applied to account for pressure losses due to the use of these dampers.

Although variable vane inlet dampers generally provide smooth airflow control down to less than 30 percent of operating-point flow, there have been instances of severe vibration on large fans when the vanes were positioned between 30 and 60 percent opening. Because vibration is aggravated by system turbulence, consideration must be given to ways of ensuring smooth airflow patterns in the duct entering the damper and leaving the fan when inlet vane dampers are employed in high-velocity systems. Variable-pitch vaneaxial fans may also be used to maintain system flow under varying pressure conditions. Variable pitch fans, however, may not qualify for safety-related seismic applications that require environmentally qualified components.

With the increase in variable air volume air conditioning systems, much has been done to improve variable speed controls for fans. Variable frequency controls, eddy current clutch motors, and mechanical adjustable speed drives are various methods of speed controls for fans. For variable air volume air conditioning systems, the airflow rate is varied to maintain a constant system pressure. For nuclear air cleaning systems, the speed of the fan is varied to maintain a constant airflow under varying system pressures.

Adjustable frequency drives are becoming more economical due to lower-cost solid state electronic components. The speed of the fan motor is directly proportionate to the frequency of the motor. Since the horsepower of the fan is a function of the cube of the speed, there can be significant secondary benefits of saving energy by using frequency drives, as well as better matching of fan performance to changing system pressure requirements.

One disadvantage of these types of speed control is a potential lack of environmental qualification data and quality assurance programs, which may be required for safety-related equipment. However, for nonnuclear-safety-related applications, these requirements do not apply and speed control is a possible option to consider.

5.6.4 Pressure Control

Effluent air cleaning systems are typically controlled to vary the system flow rate to maintain building (or space) pressure. This is accomplished by maintaining constant supply airflow and varying exhaust flow by adjusting control dampers and inlet vanes, and through speed control similar to the techniques described in Section 5.6.3. Accurately sensing building pressure and outside air pressure are important for achieving a stable operating system. The sensing system should incorporate a "dead leg" to dampen the system reaction to wind gusts. Multiple outdoor and, if necessary, indoor sensors should be provided to obtain an average outside air pressure. To maintain a building at a negative pressure with respect to the lowest outside air pressure, the outdoor sensors should be located on each exposure. The system should then be designed to control flow based on the highest positive pressure sensed (the one that would result in the most infiltration).

Sensors should be located with due consideration given to local pressure fluctuations, eddy currents, and the turbulence that can be experienced at building corners and roof edges. The ASHRAE *Handbook of Fundamentals*[3] provides guidance on determining turbulent zones due to airflow around buildings. This information must be considered in locating the sensors.

5.6.5 Qualification and Testing

All instruments used in safety-related nuclear air cleaning systems must be qualified for environmental and seismic conditions in accordance with ASME AG-1, Section IA,[1] IEEE 323,[24] and IEEE 344.[30] All instruments and devices must be calibrated and tested in accordance with the manufacturer's test procedures. In addition, all power wiring internal to control panels, except control or shielded cable, should be subjected to a high-potential test to demonstrate freedom from ground and correct wiring connections.

It is recommended that extensive onsite pre-operational testing be performed on all instrumentation and control systems associated with nuclear air cleaning systems prior to placing the systems in service. Pre-operational testing should be performed to confirm correct installation and design and to ensure correct operability of the control system and operated equipment.

5.7 Other Considerations

5.7.1 Security

Ductwork, openings for intakes and exhaust stacks, and other types of building penetrations and pathways must be properly protected against security threats. Security measures for these openings and pathways are addressed in specific site security guidelines.

5.7.2 Energy Conservation

Specialized products and components for energy conservation may be appropriately used for facility HVAC systems. In employing these components, care must be exercised to avoid using products that cannot be decontaminated or would otherwise limit the ability of the air cleaning systems to perform their design basis functions.

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